Традиційно задачі маршрутизації у мережах зв'язку вирішуються на основі скалярного підходу, при якому враховуються тільки один показник якості. Однак передача інформації у мережах зв'язку характеризується сукупністю показників якості. Тому для отримання оптимального рішення задачі маршрутизації у мережах зв'язку повинен бути використаний багатокритеріальний підхід. Це визначає актуальність розв'язання проблеми маршрутизації у мережах зв'язку з урахуванням сукупності показників якості, що характеризують якість передачі інформації. Для розв'язання цієї проблеми в даній роботі використані методи багатокритеріальної оптимізації. Запропоновано методи дискретного вибору підмножини Парето-оптимальних варіантів маршрутизації з урахуванням сукупності показників якості. При цьому виключаються безумовно гірші варіанти маршрутизації і забезпечуються потенціально можливі значення сукупності показників якості. Також це дає можливість організації багатошляхової маршрутизації, при якій забезпечується рівномірна загрузка усіх ліній зв'язку. Досліджені практичні особливості застосування вибраних методів багатокритеріальної оптимізації для вибору оптимальних маршрутів у мережах зв'язку з урахуванням сукупності показників якості. Показані переваги і обмеження багатокритеріального підходу до розв'язання проблеми маршрутизації у мережах зв'язку. Результати роботи корисні для фахівців, які займаються плануванням і проектуванням оптимальних мереж зв'язку

Ключові слова: передача інформації, мережа зв'язку, проектування, оптимальна маршрутизація, сукупність показників якості, багатокритеріальна оптимізація

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METHODS FOR MULTICRITERIAL SELECTION OF OPTIMAL ROUTES IN COMMUNICATION NETWORKS

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1. Introduction

The quality of information transmission in communication networks largely depends on the applied routing protocols that determine the ways and techniques for information transmission. In this case, it is necessary to take into consideration some quality indicators characterizing, as a rule, contradictory technical and economic requirements to information transmission in communication networks. This becomes possible when designing routing protocols, which are based on using the methods for multicriterial optimization in choosing optimal routes in communication networks.

In known studies [1–6], when solving the problem of routing in communications networks, the scalar approach based on taking into consideration only one quality indicator is used. This determines the relevance of the studies aimed at the solution of the problem of optimal routing in communications networks, taking into consideration the totality of quality indicators by using the methods for multicriterial optimization.

2. Literature review and problem statement

Paper [1] considers the theoretical and practical issues of constructing ad-hoc and sensor networks. It is noted that the efficient operation of these networks depends largely on the choice of routing protocols. Study [2] reports an analysis of the characteristics of possible routing protocols that are used in mobile ad-hoc networks. In work [3], the issues of effective distribution of the infrastructure of multipath network of wireless mobile phones charging are studied. Research [4] discusses the multipath routing protocol that ensures stability of information transmission in cognitive radio networks. Paper [5] deals with specific features of occurrence of mutual interference at optimal single-step routing for the organization of the D2D connection. Study [6] focuses on considering the optimal routing strategy for transport networks in order to ensure the constant cost of information transfer and high throughput of a network.

It follows from the specified papers that organization of routing in communication networks, especially in specialized communication networks, specifically ad-hoc, sensor and cognitive networks, significantly influences the efficiency of their operation. It should be noted that in these papers, the construction of routing protocols with a view to facilitating their implementation is based on taking into consideration only one quality indicator. Currently, however, there is a need to improve the operation efficiency of communication networks by selecting the optimal routes, taking into consideration some quality indicators, which tend to have antagonistic character. In order to address the specified problem of optimal routing in communication networks, it is necessary to use the methods for multicriterial optimization.

Paper [7] provides the theoretical framework for multicriterial optimization, while paper [8] considers particular problems of the combinatorial optimization. Article [9] describes one of the multicriterial optimization methods – the method of hierarchy analysis. Hence, there is a need, based on the general theoretical provisions of multicriterial optimization, to develop and explore the methods suitable for the multicriterial discrete choice of routing variants in communication networks, taking into consideration the totality of quality indicators.

Research [10] deals with the methods for choosing a subset of Pareto-optimal design options, as well as the methods for narrowing the Pareto subsets to a single preferred option taking into consideration the totality of quality indicators. Here, the features of using these methods for solving different types of problems of multicriterial choice of the optimal variants when designing various types of the means of communication are studied.

3. The aim and objectives of the study

The aim of this study is to identify the theoretical and practical features of application of the methods for multicriterial optimization to solve the problem of optimal routing in communication networks taking into consideration the totality of quality indicators.

To accomplish the aim, the following tasks have been set:

– to propose and explore the theoretical features of the methods for selection of a subset of Pareto-optimal routes variants in communication networks, taking into consideration the totality of quality indicators;

– to explore the practical features of the multicriterial approach to solving the problem of optimal routing in communication networks, taking into consideration the totality of quality indicators;

– to compare the results of multicriterial selection of optimal routes with the case of scalar approach to solving the problem of routing in communication networks.

4. Methods for discrete selection of a subset of Pareto-optimal design variants taking into consideration the totality of quality indicators

The problem of making optimal design solutions when designing systems is to choose among the original set of systems such options that are, in a sense, the best, i. e. optimal with taking into consideration the totality of quality indicators. We will present briefly, based on paper [10], the methods for multicriterial optimization of the systems that can be applied for multicriterial choice of optimal routes in communication networks.

Each design solution is characterized by a certain degree of achievement of the aim. The optimal solution is a solution that is preferable to other alternative solutions. Setting an optimality criterion for systems for finding the best option on the set of the admissible ones is associated with formalization of the idea about the optimality of a system. In this case, there are two approaches to determining the concept of optimality of design solutions: ordinalistic and cardinalistic.

Ordinalistic approach to determining the concept of optimality of design solutions is based on the introduction of the concept of binary relations, which allows formalizing operations of pair-wise comparison of alternatives and selection of optimal solutions.

Consider the features of choosing a set of optimal solutions for a particular case of the ratio of strict preference $\succ$. *The set of optimal solutions* in relation to strict preference $\succ$ includes solutions $x^{\circ}\in X$, for which there exist no other solutions $x\in X$, for relation $x\succ x^{\circ}$ to be true. This set of optimal solutions is denoted by X. Depending on the structure of set X and properties of relation $\succ$, set of optimal solutions $opt_{\succ}X$ can contain a single element, finite or infinite number of elements. If set X is not empty and contains a finite number of elements, and binary relation $\succ$ is asymmetrical and transitive, this set is non-empty $opt\succ Z\neq\varnothing$.

Cardinalistic approach to determining the concept of optimality of design solutions is based on the introduction of some objective function $U(.)$, the value of which is interpreted as a utility (value) of solution x and determines the preference of the DM. The chosen objective function sets the appropriate relation of order R on set X. The value of objective function $U(.)$ is preference indicator R. Specifically, when assigning the scalar-valued objective function, it is considered that design solution x' is preferred to alternative solution x'' and only if condition $U(x')>U(x^{\circ})$ is satisfied. Using such an approach, it is possible to assign a formalized procedure for selecting optimal design solutions (optimality criterion) from conditions of extremum (minimum or maximum) of the objective function on the set of admissible solutions:

$$X^{o}=\arg\underset{x\in X}{extrem}\left[U\left(x\right)\right]. \tag{1}$$

In this case, to select optimal design solutions, one uses the methods of scalar optimization, which, as a rule, lead to the choice of a single design solution.

However, due to the lack of certainty of the view on optimality taking into consideration the totality of contradictory demands to design solutions, it is often impossible to assign a scalar objective function and corresponding scalar criterion of optimality in the formalized way. That is why at the initial stages, design solutions are characterized by vector objective function, including the totality of particular objective functions:

$$\vec{f}(x)=\left(f_1(x),f_2(x),...,f_m(x)\right), \quad (2)$$

that determine the utility (value) of design solution x from the point of view of different requirements. In this case, there emerge more complex problems of optimization of solutions by the totality of quality indicators, which are also called by the problems of multicriterial or vector optimization:

$$X^{(o)}=\arg_{x\in X} extrem\left[\vec{f}(x)=\left(f_1(x),f_2(x),...,f_m(x)\right)\right]. \quad (3)$$

In multicriterial problem (3), the following variants are possible:

– particular objective functions are independent on each other;

– functions are related with each other and are agreed;

– functions are related to each other and are antagonistic. In the first two cases, optimization problem (3) is reduced to the totality of independent scalar optimization problems for particular objective functions. In the latter case, which is common in practical applications, optimization problem (3) is reduced to finding an agreed extremum of particular objective functions. This extremum means that further improvement of the value of each objective function can be achieved only at the expense of worsening the values of other objective functions. As a result, a subset of solutions that are optimal by totality quality indicators is found.

With the introduction of the vector objective function, along with a set of admissible alternative design solutions X, one also considers the set of values for this function corresponding to them:

$$Y=\vec{f}(X)=\left\{\vec{y}\in Y\,|\,\vec{y}=\vec{f}(x),x\in X\right\},Y\subset R^m, \quad (4)$$

which is called the set of vector estimates or *criterial space*.

One estimate $\vec{y}=\vec{f}(x)\in Y$ corresponds to each solution $x\in X$. On the other hand, alternative solutions $x\in X$ (there can be more than one), for which $f(x)=y$ match each estimate. Thus, there is a close relation between sets X and Y and that is why the choice of the optimal design solutions on set X in the specified sense is equal to the choice of the corresponding optimal estimates in the criterial space Y.

For vector estimates $\vec{y}'$ and $\vec{y}''$ of space Y, it is possible to consider different types of binary relations, specifically, one widely uses:

– relation of non-strict preference (also called a Pareto relation):

$$\vec{y}'\Phi_1\vec{y}''\leftrightarrow\vec{f}(x')\geq\vec{f}(x''),\ \ f_i(x')\geq f_i(x''),$$

$$i=\overline{1,m},\ \ f_i(x')\neq f_i(x''); \quad (5)$$

– relation of strict preference (also called a Slater relation):

$$\vec{y}'\Phi_1\vec{y}''\leftrightarrow\vec{f}(x')>\vec{f}(x''),\ \ f_i(x')\geq f_i(x''),\ \ i=\overline{1,m}. \quad (6)$$

When making decisions, it is desirable to get the extreme value for each of particular objective functions $f_1(x),f_2(x),...,f_m(x)$. Extremum point on set X simultaneously for all objective functions is an *a priopi* optimal multicriterial problem. In practice, however, this case occurs very rarely. That is why, in the absence of additional information about preferences $\succ x$ and $\succ y$ in the multicriterial problem, it is possible to find only agreed extremum of particular objective functions, to which a set of optimal solutions corresponds. The agreed extremum of the totality of objective functions means that further improvement of the values of each of them can be achieved only at the expense of worsening other objective functions.

Pareto-optimality. In multicriterial optimization problems, binary relation $\geq$ plays an important role. That is why the totality of optimal estimates for binary relation $\geq$ on set Y has a special name: *a set of Pareto-optimal (optimal for Pareto)* or *effective estimates*. This set is designated through $P(Y)=opt_{\geq}Y$. Inclusion $\vec{y}^{(o)}\in P(Y)$ occurs only when there are no other estimates $\vec{y}\in Y$, for which vector inequality $\vec{y}\geq\vec{y}^{(o)}$ will be satisfied.

Corresponding solution $x^{(o)}\in X$, for which inclusion $\vec{y}^{(o)}=\vec{f}(x^{(o)})\in P(Y)$ is true, is called *Pareto optimal (optimal for Pareto)* or an *effective solution* relative to vector function f on set X. The set of all these solutions are designated through $P_f(X)$. Thus, inclusion $x^{(o)}\in P_f(X)$ occurs only when there are no other such estimates $x\in X$, that inequality $\vec{f}(x)\geq\vec{f}(x^{(o)})$ is satisfied.

At $m=1$, binary relation $\geq$ turns into relation $>$ for numbers and Pareto-optimal estimate coincides with extreme element of the numeric set, which corresponds to extremum of the scalar function. Thus, the notion of a Pareto-optimal point can be seen as a generalization of the notion of an extremum in case of some functions.

The methods for finding Pareto-optimal design solutions. Pareto-optimal solutions can be found both directly on the set of design solutions with the use of the introduced binary relations of preference, and in the space of the introduced quality indicators – in the criterial space of the estimates of these quality indicators.

At a finite power of the set of admissible design variants, a subset of Pareto-optimal estimates and corresponding solutions can be found using the *method of discrete choice*, which is determined by the following formal procedure:

$$P(Y)=opt_{\geq}Y=\left\{\vec{k}(\varphi^o)\in Y:\exists\vec{k}(\varphi)\in Y:\vec{k}(\varphi)\geq\vec{k}(\varphi^o)\right\}. \quad (7)$$

When finding a subset of Pareto-optimal estimates according to (7), the unconditionally worst estimates are excluded, and therefore, the unconditionally worst variants of the system corresponding to them.

In addition, in order to find Pareto-optimal solutions, other special methods, specifically, the weight method, method of operating characteristics, the method of successive concessions, and the method of the main criterion can be used.

In the case of the application of the *weight method*, Pareto-optimal design solutions are found by optimizing the weighted sum of particular objective functions:

$$P_{\vec{k}}(\Phi_\partial)=$$

$$=\left\{\varphi^{(o)}\in\Phi_\partial:\arg_{\varphi\in\Phi_\partial} extr\begin{bmatrix}k_p(\varphi)=\lambda_1k_1(\varphi)+\lambda_2k_2(\varphi)+\\+...+\lambda_mk_m(\varphi)\end{bmatrix}\right\}, \quad (8)$$

in which weight coefficients $\lambda_1,\lambda_2,...,\lambda_m$ are selected from condition:

$$\lambda_i>0,\ \sum_{i=1}^{m}\lambda_i=1.$$

The set of Pareto-optimal solutions contains those variants of the system, which satisfy condition (8) at different admissible combinations of weight coefficients $\lambda_1, \lambda_2, ..., \lambda_m$.

The method of operating characteristics implies that all objective functions but one, for example, the first one, are transferred to the category of constraints of the equality type and an extremum is found on the set of admissible alternatives Φ_{ad}:

$$P_{\vec{k}}(\Phi_{ad}) = \left\{ \begin{matrix} \varphi^{(o)} \in \Phi_{ad} : \arg \underset{\varphi \in \Phi_\partial}{extr} \left[k_1(\varphi) \right], k_2(\varphi) = K_{2f}; \\ k_3[\varphi] = K_{3f}, ..., k_m(\varphi) = K_{mf} \end{matrix} \right\}. \quad (9)$$

Here, $K_{2f}, K_{3f}, ..., K_{mf}$ are some fixed but arbitrary values of quality indicators.

The optimization problem (9) is solved sequentially for all admissible combinations of values $K_{2f}, K_{3f}, ..., K_{mf}$. In this case, one determines a subset of Pareto-optimal design variants and corresponding multi-dimensional working surface in criterial space, which resulted under certain conditions, coincides with the Pareto-optimal surface. It should be noted that each point on the Pareto-optimal surface has the property of *m*-multiple optimum agreed by Pareto. A potentially achievable value of one of indicators k_{opt} at fixed (corresponding to this point) values of the rest $(m-1)$ of quality indicators corresponds to each point of this surface. Pareto-optimal surface can be described by any of the following ratios:

$$k_{1opt} = f_{no}^{1}(k_2, k_3, ..., k_m), ..., k_{mopt} = f_{no}^{m}(k_1, k_2, ..., k_{m-1}), \quad (10)$$

which are multidimensional diagrams of the exchange between quality indicators demonstrating how a potentially attainable value of the corresponding indicator depends on potentially achievable values of other quality indicators.

Multidimensional potential characteristics of a system. The concept of Pareto-optimality is fundamental to the theory and practice of multicriterial optimization of systems. The Pareto-optimal surface, obtained using one of the methods, connects potentially achievable values of indicators and is an agreed optimum for Pareto values of systems quality indicators, which in the general case are dependent and competing with each other. That is why determining the Pareto-optimal surface in the criterial space, thus we find multidimensional potential characteristics (MPC) of a system and multidimensional exchange diagrams (MED) related to them.

Compared to the commonly used one-dimensional potential characteristics of a system, the MPC give qualitatively new information for analysis of design solutions, as they give the idea of potentially possible values of the totality of indicators and potential capabilities of a system. Analyzing the MED, it is possible to figure out how to change the values of some indicators of the system quality for the sake of the improvement of other indicators, as well as how to change the structure and parameters of the corresponding systems in this case.

If the found subset of Pareto-optimal variants of the system proved to be narrow, it is possible to use any of them as the best option. In this case, it is possible to assume that relation of strict preference in the space of admissible variants of a system $\succ$ coincides with the relation of preference in the criterial space of estimates $\geq$ and that is why $opt_{\succ} Y = P(Y)$. However, in practice, a subset of Pareto-optimal estimates $P(Y)$ often proves to be rather broad. This means that although preference relations $\succ$ and $\succ$ are connected by the Pareto axiom, they do not coincide. In this case inclusions $opt_{\succ} Y \subset P(Y)$, as well as $opt_{\succ} \Phi \subset P_{\vec{k}}(\Phi_\partial)$ are true.

That is why in a series of problems of designing systems, there arises a need to narrow down the found subset of Pareto-optimal solutions to the single variant of design solution. To do this, the conditional preference criteria, based on different methods of Pareto subset narrowing can be used. However, the final selection of a single design solution should be made within the found subset of Pareto-optimal systems, which is obtained by excluding unconditionally worst variants of the system.

This raises the question: does it make sense to make a choice based on unconditional preference criterion (the Pareto criterion), if subsequently it is necessary to introduce the conditional preference criterion to select the single route. To justify the appropriateness of introduction of the stage of finding Pareto-optimal variants, it is necessary to note:

– the application of the UPC gives the possibility to find all Pareto-optimal routes, while rejecting all unconditionally worse routing variants;

– the application of UPC provides an opportunity to find potentially best possible values for each of quality indicators and the relationship between them;

– even if choosing the only route variant, it is necessary to introduce the conditional preference criterion, it is better to introduce all sorts of conditionality at a later stage of selection.

5. Statement of a multi-criteria approach to the choice of optimal routes in communication networks

Consider the following multicriterial problem of routing optimization in communication networks. Let a set of admissible solutions (routes) be determined on the graph of network $X = \{x\}$, which is called discrete, if set X is finite or countable.

Solutions $x \in X$ in the form of subgraphs $x = (V_x, E_x)$ $(V_x \in V,\ E_x \in E)$ for multi-vertices graph $G = (V, E)$, which satisfies the assigned constraints, will be admissible. It is supposed that vector objective function $\vec{F}(x) = (F_1(x), ..., F_\nu(x), ..., F_m(x))$, the constituents of which determine quality indicators of the quality of routes, is assigned on subset X. As a rule, quality indicators are related to each other and antagonistic. In this case, the variants of routes that are optimal by the totality of quality indicators form a set of Pareto-optimal alternatives of solving the route problem, to which the agreed optimum of particular objective functions correspond:

$$F_1(x), \ldots, F_\nu(x), \ldots, F_m(x). \quad (13)$$

Consider the features of the choice of optimal routes in a communication network consisting of nodes and communication lines connecting the nodes. This network is represented by graph $G = (V, E)$, where V is the set of nodes, E is the set of communication lines. Each line e is characterized by indicators of service quality k_l, to which it is possible to put in line weight functions $w_l(e)$ with assigned constraints $w_l(e) \leq c_l \lim\limits_{x \to \infty}, l = \overrightarrow{1, m}$. To take into consideration the totality of indicators of service quality, it is proposed to use the scalar objective function e in the form of:

$$F(e) = \lambda_1 w_1(e) + \ldots + \lambda_i w_i(e) + \ldots + \lambda_m w_m(e), \quad (14)$$

where $\lambda_i > 0,\ \sum_{i=1}^{m} \lambda_i = 1$.

In this case, it is necessary to solve the problem of finding the optimal path (route) p from the source node s to target node t by finding an extreme value of the objective function of the route:

$$extr\left(w(p) = \sum_{j=1}^{N} F_j(e) \right), \tag{15}$$

where N is the number of communication lines, included in the route.

The obtained Pareto-optimal variants of the routes are equivalent in terms of the unconditional preference criterion (UPC) – the Pareto criterion. That is why each of them can be used for solving the problem of multipath routing, which will enable to load evenly the communication lines with the corresponding kinds of traffic with the required quality of service.

6. Results of multicriterial selection of optimal routes in communication networks

We considered the practical features of solving a stated multicriterial routing problem on the example of studying a fragment of the communications network, shown in Fig. 1. The model of the studied network consisted of twelve nodes linked with one another by communication lines with losses. The research was conducted by simulation in the software packet Network Simulator. Information packets were formed and passed from node 0 to all other nodes in the network according to the specified routing method, based on the multicriterial or the scalar approach to the selection of optimal routes. The packets were transmitted at the speeds of 64 Kbps, the size of the transmitted packets amounted to 210 bytes. Each communication line had the throughput of 128 Kbps.

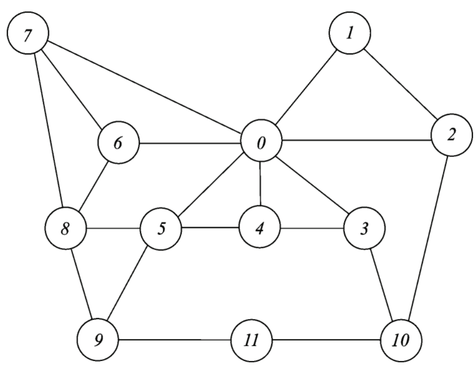

Fig. 1. Fragment of the examined communication network

The following indicators of traffic service quality that characterize each communication line were selected: packet delay time, packet loss rate, cost of using a communication line. The values of these quality indicators were evaluated in the course of modeling of the studied communications network.

It was believed that time of delay of packet transmission is largely determined by the length of a communication line. The packet loss rate depends on the model of losses introduced in each line. The cost of using the line depends on the time of delay on the line, the magnitude of losses and intensity of using. The quality indicators of communication lines normalized to maximum values are shown in Table 1.

Analysis of the network graph (Fig. 1) shows that for each target node, there are a great number of variants of choosing the routes, even on condition of impossibility of re-visiting the node passed.

Table 1

Quality indicators of communication lines normalized to maximum values

Communication line	Time of delay of packet transmission	Packet loss rate	Cost of using the communication line
0–1	0.676	1	0.333
0–2	1	0.25	1
0–3	0.362	1	0.333
0–4	0.381	0.25	1
0–5	0.2	1	0.333
0–6	0.19	1	0.333
0–7	0.571	0.25	1
7–6	0.4	0.25	0.333
7–8	0.362	0.25	0.667
8–6	0.314	0.5	0.5
8–5	0.438	0.25	0.333
8–9	0.248	0.5	0.333
9–5	0.257	0.25	1
9–11	0.571	0.25	0.667
11–10	0.762	0.25	0.333
5–4	0.381	0.25	0.667
2–10	0.457	0.25	0.333
3–10	0.79	0.25	0.333
4–3	0.286	0.25	0.333
1–2	0.448	0.25	0.333

Selection of Pareto-optimal routes. To solve the problem of choosing the Pareto-optimal routes, we applied the weight method with the use of the following quality indicators: k_1, reflecting the length of the line; k_2, reflecting the packet loss rate; k_3, reflecting the cost of using communication lines.

The subset of the Pareto-optimal routes was obtained during the minimization of expression (2) with all sorts of combinations of weight coefficients. To illustrate, Fig. 2 shows a set of variants of routes between nodes 0 and 8 in the criterial space of quality indicators k_1 and k_2. The left lower boundary including three points corresponds to the set of Pareto-optimal solutions. It is easy to see the Pareto-agreed optimum of quality indicators (minimum possible value of one quality indicator at the assigned fixed values of another indicator) corresponds to them. This boundary is also a diagram of exchange of quality indicators, which shows how a potentially achievable value of one of the quality indicators depends on the value of another indicator.

It is possible to use the resulting subset of Pareto-optimal route options in order to organize multipath routing and to choose optimal routes for transmission of corresponding traffic with the required service quality.

To choose a single route variant from the subset of Pareto-optimal, we used the conditional preference criterion based on the *utility theory* in the form of (11). At the values of coefficients of relative importance of quality indicators c_1=0.3; c_2=0.3; c_3=0.4, the only preferable variant of the route from node 0 to node 8 was chosen.

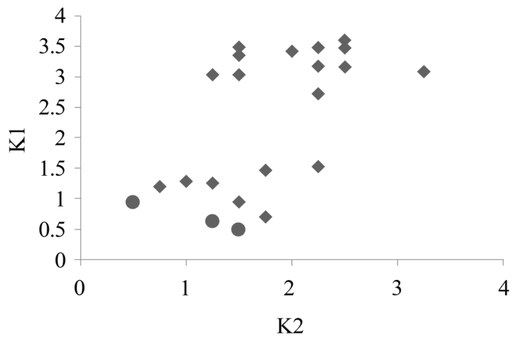

Fig. 2. Mapping of the set of variants of routes between nodes 0 and 8 into criterial space of two quality indicators

6. Discussion of the results of multicriterial choice of optimal routes

The feature of the proposed multicriterial approach to solving the problem of choosing the optimal routes is strict accounting on the formalized level of the totality of contradictory technical and economic requirements for routing in communications networks. Multicriterial routing optimization ensures obtaining potentially possible values of quality indicators of routes. In addition, it enables the organization of multipath routing, which provides the possibility of the uniform loading of all communication lines. Comparative studies on the selected model of a communication network show the merits of the multi-criteria approach taking into consideration the main selected quality indicators. Specifically, there was a gain in the indicator of packet loss rate (by 3 times) and in the indicator of the cost of using communication lines (by 1.5 times) compared to the scalar approach implemented in the well-known routing protocol of the OSPF. Characteristically, for this protocol, the gain only in one (scaler) indicator of time delay was obtained. However, in this case, other quality parameters are not taken into account, which is a drawback of this protocol.

In the future, it is planned to continue the experimental research into the multicriterial approach to routing in actual communication networks, taking into consideration different types of quality indicators. Based on the results of the research, practical guidelines on the implementation of the proposed methods of multicriterial optimization in solving the problems of optimal routing in different types of networks will be developed.

7. Conclusions

1. The solution to the problem of optimal routing in communication networks, taking into consideration the totality of quality indicators using the methods of multicriterial optimization was proposed. The subset of Pareto-optimal variants of routes, for which the agreed optimum of the totality of quality indicators is true, is the optimal solution of the problem. It is possible to use the resulting subset of Pareto-optimal routes for the organization of multipath routing, which will make it possible to ensure the uniform load of a communication line.

2. The practical features of using the multi-criteria approach to solving the problem of optimal routing on the example of a fragment of a communication network were studied. We obtained a gain in the indicator of packet losses (by 3 times) and in the indicator of the cost of using communication lines (by 1.5 times) compared to the scalar approach implemented in the well-known OSPF routing protocol.

3. The constraint of the proposed solution to the problem of optimal routing in communication networks, taking into consideration the totality of quality indicators is a complication of the routing procedure.

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