UDC 381.324

METHODS OF MULTI-CRITERIA OPTIMIZATION IN PLANNING NETWORKS OF MOBILE COMMUNICATION

Valerii M. Bezruk, Daryna V. Chebotarova

Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

The features of the use of multi-criteria optimization methods to solve design problems of mobile communication networks are considered. The article is aimed to solve the relevant scientific and applied problem of planning and optimization of cellular mobile communication networks along with taking into account the totality quality indices, based on the application of multicriterial optimization methods. Examples illustrating how to select optimal design decisions while networks of mobile communication planning taking into account the totality of quality indices are given.

Introduction

Planning is an important stage of designing networks of mobile communication (NMC), which substantially determines execution of conflicting requirements of the operator. Thus it is necessary to take into account the totality of quality indices, defining the necessity of the multi-criteria approach when choosing optimal design solutions. But the present methods and software do not consider the process of planning NMC as the task of a multi-criteria optimization [1-3].

The multi-criteria analysis and optimization are advanced enough in different technical fields, but they are still insufficiently widely utilized in telecommunications, in particular, at NMC planning. One of the reasons is, that the designers have not completely realized broad possibilities of computing mathematical methods of the multi-criteria optimization and increasing possibilities of computers when solving the practical tasks of choosing optimal design solutions at NMC planning taking into account a totality of quality indices [4-6].

The given paper contains the survey of theoretical and practical aspects of optimal design solutions choice taking into account a totality of quality indices. The presented methods of the optimal design versions choice are based on the multi-criteria optimization theory. Some features of the problem solving the multi-criteria optimization of design solutions at planning networks of mobile link of 2G, 3G and 4G generations are given.

1. Methods of multi-criteria choice of optimal design versions

Let's consider some features of the methodology of choosing optimal design versions of the technical system taking into account a totality of quality indices [6]. There are two approaches when setting the system optimality criterion: ordinal and cardinal optimality criteria.

The ordinal approach operates with the concept of order (better - worse) and is based on introduction of some binary relations on a set of valid design solutions Φ_∂. Thus the solution $\varphi^{(o)} \in \Phi_\partial$ is named as an optimal one by the binary relation of a strict preference $\succ$, if there are no other existing solutions $\varphi \in \Phi_\partial$, for which the ratio $\varphi \succ \varphi^{(o)}$ would be fair. A subset of all optimal solutions under the ratio $\succ$ is labeled by $opt_{\succ}\Phi_\partial$.

The cardinal approach to the description of preference assigns some numerical value of the function $k(\bullet)$, defining value of the version φ, to each version $\varphi \in \Phi_\partial$. Each importance function defines the appropriate order (or preference) R on set Φ_∂ $(\varphi' R \varphi'')$ only in a case, when $k(\varphi') \geq k(\varphi'')$. In this case they say, that the criterion function $k(\bullet)$ is the estimation tool of design version preference $\succ$. Thus, the procedure of choosing the optimal design variant $\varphi^{(i)}$ is defined by the relation $\varphi^{(i)} = \arg \underset{\varphi \in \Phi_a}{extr} \left[k(\varphi) \right]$.

In many cases because of poor original idea of optimality of design versions it is impossible to establish the scalar criterion of optimality in the formalized form resulting in the choice of the unique design solution $\varphi^{(i)}$. Therefore, on the initial stages of planning the value of the design versions is characterized not by one, but some set of quality indices and the vector criterion function bound with them

$$\vec{k}(\varphi) = (k_1(\varphi), .k_2(\varphi), \ldots, k_m(\varphi)) . \quad (1)$$

It is important to note that the quality indices of the system can be of three types: neutral, coordinated between themselves and contesting (antagonistic) between themselves. In the first two cases the optimization of the network can be separately fulfilled by each quality index. In the third case the reaching of the potentially possible value of each quality index separately can appear inaccessible. Thus just the coordinated optimum of contradictory between themselves criterion functions (optimum by the Pareto criterion) can be reached. Such optimum implies that the potentially possible value of each quality index is reached separately without deterioration of other quality indices of the network. Thus the further improvement of quality indices can be reached only at the expense of deterioration of other quality index. The system versions non-dominated by the Pareto criterion correspond to the compounded optimum of quality indices values.

Method of discrete choice of the Pareto subset. The formalized procedure of obtaining the subset of Pareto-optimal design versions in a criteria space $V = \vec{k}(\Phi_a)$ is defined by discrete search of versions according to the relation

$$P(V) = (\vec{k}(\varphi^o) \in V \left| \forall \vec{k}(\varphi) : \vec{k}(\varphi) \geq \vec{k}(\varphi^o)\right.).$$
(2)

The considered task of choosing the subset of Pareto-optimal design versions taking into account a quality of quality indices is the task of the multi-criteria (vector) optimization. As a rule, the Pareto subset, found as a result of solution, contains not one version but some set of optimal design versions

Potentially possible quality indices values, corresponding to the compounded optimum by Pareto, represent the multivariate potential characteristics of the designed system. In the criteria space of quality indices the totality of Pareto-optimal values represents the Pareto-optimal surface and multivariate diagrams of exchange of the chosen quality indices of the system bound with it.

Finding of the system design versions optimal by the Pareto criterion can be realized either, according to (2), on the set of valid versions of Φ_∂ or with the use of special methods, for example, the weight method, the method of performance, the method of successive concessions etc.

Weight method of the Pareto subset finding. With the use of this method the Pareto-optimal solutions are found through optimization of the weighted sums of the criterion functions

$$\underset{\varphi \in \Phi_\delta}{extr}[k_p(\varphi) = \lambda_1 k_1(\varphi) + ... + \lambda_m k_m(\varphi)], \quad (3)$$

where the weight coefficients $\lambda_1, \ldots, \lambda_m$ are selected on the basis of the condition $\lambda_i > 0, \sum_{i=1}^{m} \lambda_i = 1$. The Pareto-optimal solutions are versions, which meet (3) at different admissible combinations of weight coefficients $\lambda_1, \ldots, \lambda_m$.

Method of performance for finding the Pareto subset. This method includes optimization of one criterion function, in particular, the first one, provided that the remaining ones are referred to the category of constraints of the equality type

$$k_{1opt} = \underset{\varphi \in \Phi_\delta}{extr}[k_1(\varphi)], \; k_2(\varphi) = K_{2f}, ..., k_m(\varphi) = K_{mf}.$$
(4)

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

The problem of optimization (4) is solved sequentially for all valid combinations of the specified values $K_{2f}, ..., K_{mf}$. As a result, a multivariate performance is found in the criteria space

$$k_{1opt} = f_p(K_{2\varphi}, K_{3\varphi}, ..., K_{m\varphi}). \quad (5)$$

If the found dependence (5) monotonically decreases for each of the parameters, the effective area coincides with the Pareto-optimal plane. This plane can be coherent, incoherent or isolated group of points.

The formal model of the Pareto-optimization task does not contain the information for choosing the unique version. The set of valid design versions is narrowed down only to a subset of the Pareto-optimal solutions at the expense of exclusion of certainly worse versions by unconditional criterion of preference (the Pareto optimality criterion).

In principle, each version from of the subset of Pareto-optimal design versions can be chosen for further stages of the system design, as they are incomparable by the Pareto unconditional criterion. If only one version of the system should be selected for the subsequent design stages and implementation there is a necessity to narrow down a subset of the Pareto-optimal solutions up to the unique design version. Some additional information about preferences of the system customer should be used for this purpose**.** This information becomes accessible after the comprehensive analysis of the Pareto-optimal design versions, in particular, the structure and parameters of the system, performance of the obtained versions of the system, relative importance of the quality indices etc. The obtained additional information is used for creation of the conditional criterion of preference in the form of the scalar criterion function, optimization of which leads to the choice of the unique design version of the system from the Pareto subset.

Choice of the unique design version from the Pareto subset with the use of the scalar importance function. One of frequently used methods for contraction of the Pareto-optimal solutions subset up to the unique design version is based on creation of the scalar importance function of $F(k_1,..,k_m)$ m variables. Such a function is selected, the values of which the binary ratio $\succ$ corresponds to in case if for arbitrary estimates $\vec{k}^{'}, \vec{k}^{''} \in V$ the inequality $F(\vec{k}^{'}) > F(\vec{k}^{''})$ is fulfilled when and only when the binary relation $\vec{k}^{'} \succ \vec{k}^{''}$. is fulfilled. The importance function can be written as follows

$$F(k_1,...,k_m) = \sum_{j=1}^{m} c_j f_j(k_j), \qquad (6)$$

where c_j - are the scale factors defining relative importance of the corresponding quality indices, $f_j(k_j)$ - are some one-dimensional importance functions, which are estimates of importance of the system version φ from the point of view of the quality index $k_j(\varphi)$.

Choice of the unique design version from the Pareto subset based on the fuzzy sets theory. This method is based on that such a notion as “the best version of the system” can not be precisely defined because of the initial uncertainty concerning preferences of the customer. This notion can be considered as a fuzzy set and to estimate the design versions it is possible to utilize fundamentals of the fuzzy sets theory. In a certain sense the universal form of the membership function, interpreted from the point of view of the fuzzy sets theory relative to a set of quality index, can be written as

$$\xi_{\vec{k}}(k_1,...,k_m) = \frac{1}{m}\left\{\sum_{l=1}^{m}[\xi_{k_j}(k_j)]^{\beta}\right\}^{\frac{1}{\beta}}. \qquad (7)$$

The advantage of such form is that depending on the β parameter value a wide class of the membership function is implemented: from the linear additive form with $\beta = 1$ up to purely nonlinear one with $\beta \to \infty$.

Choice of the unique design version from the Pareto subset based on lexicographic relations. Sometimes it is desirable for the customer to receive the maximal value of one of the quality indices of the system, for example, k_1 irrespective of the values of other quality indices. It means that the quality index k_1 is more important for it than the remaining indices. Such case is also possible, that the whole group of indices $k_1,\ldots,k_m$ can be strictly ordered from the standpoint of their importance. In particular, a number of such judgments is possible: the indicator k_1 is more important than other indices $k_2,\ldots,k_m$; the index k_2 is more important than other indices $k_3,\ldots,k_m$, etc. This corresponds to the definition of the lexicographic relations, which can be applied to compare the obtained Pareto-optimal design versions**.**

2. Some examples of application of multi-criteria choice methods for optimal design versions in planning NMC

Let's consider some practical features of application of the multi-criteria optimization methods to planning NML. The process of search of the optimal design versions in planning NMC, taking into account the formalized registration of a totality of quality indices, includes the following stages:

- specification of a set of input data for valid design versions of NMC, which include: the radio standard, occupied bandwidth, the number of active subscribers, area of coverage, sectoring and antennas height, base stations transmitters power, parameters of radio waves attenuation etc.;
- definition of a set of valid design versions taking into account limitations on NMC structure and parameters;
- specification of NMC quality indices and calculation of their values for valid design versions;
- selection of the Pareto-optimal design subset versions of NMC in a criteria space of estimates of quality indices values;
- analysis of the obtained Pareto-optimal design versions, multivariate potential characteristics and multivariate chart of exchange of NMC quality indices;
- creation of the conditional criterion of preference with the obtained additional information and selection of the unique design version of NMC.

Multi-criteria choice of optimal design solutions in planning 2G NMC radio network. The example of applying the multi-criteria optimization methods in the nominal stage of planning of the NMC radio network of the GSM standard is considered [4]. The set of valid NMC versions was formed. Thus, different input data including the planned amount of subscribers in the network, size of the coverage area, the subscribers’ activity at the hour of the maximum load, occupied bandwidth, sizes of clusters, possible probability of calls blocking and percent of link deterioration time were specified.

The following quality indices were chosen: an error probability, the network capacity, amount of base stations in the network, efficiency of the radio-frequency spectrum use, probability of blocking, area of coverage. The subset of the Pareto-optimal versions including 71 NMC design versions was chosen in the criteria space of estimates of the mentioned quality indices. Thus, 29 certainly worse design versions were eliminated. The unique design version of NMC among the Pareto-optimal subset was chosen from a condition of minimization of conditional criterion of preference (6). It is characterized by the following data: an amount of the subscribers - 30000; area of service - 320 km^2; the subscribers activity - 0.025 Erl; the occupied bandwidth - 4 MHz; possible probability of the call blocking - 0.01; percent of time of the link deterioration - 0.07; density of service - 94 active subscribers per km^2; a cluster size - 7 honeycombs; an amount of the base stations in the network - 133; an amount of the subscribers served by one base station - 226; a traffic - 3.326 Erl; an error probability - 5.277 10^{-7}.

As results of Pareto-optimization, there were obtained multivariate patterns of exchange (MPE) of the quality indices, being of antagonistic character. For illustration, some MPE are presented at fig. 1. Each MPE point defines the potentially best values of each index which can be attained at fixed but arbitrary values of other quality indices. MPE also show how the improvement of some quality indices is achieved at the expense of other.

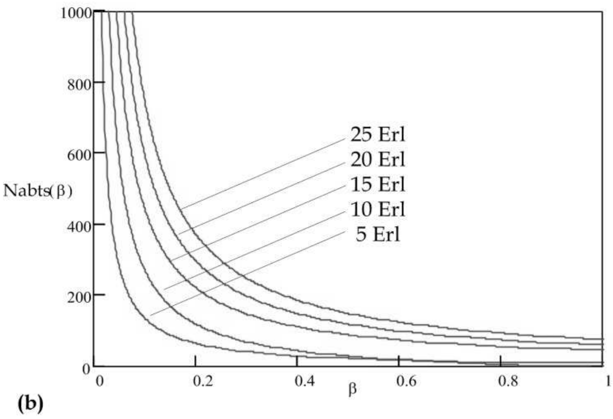


Fig. 1. MPE of the quality indicators (the number of subscribers serviced by one base station, the load, the activity of subscribers (b) for NMC of GSM standard)

Multi-criteria choice of optimal design solutions in planning 3G NML radio network. The features of solving the task of the radio network optimization by a set of quality indices at a nominal stage of planning of the NMC radio network of the UMTS standard were considered [5]. The set of valid design versions, defined by various input data, in particular, by the planed amount of subscribers in the network, area of the served territory, probable activity of the subscribers, valid probability of the call blocking, was formed. The radio network quality indices were specified: probability of denial of service, density of the served subscribers and necessary amount of the base stations. A set of valid design versions is mapped in the criteria space of estimates of quality indices**.** The Pareto-optimal solutions subset including 5 design versions was singled out. The unique design version of the NMC radio network was chosen from this subset with the help of the lexicographic approach; this version is characterized by the following data: probability of the blocking - 0,02; density of the served subscribers - 183 subscr. /km^2, amount of the base stations - 18.

*Multi-criteria choice of optimal design solutions in planning NMC transport network***.** Results of the optimization task solution of the NMC transport network topology were obtained by two quality indices: the unavailability factor and relative cost of the transport network [5]. In the considered example a set of valid versions of the transport network topology was formed for the nominal schedule of the radio network containing 26 base stations and 1 base controller. The estimates of the introduced quality indices were found for each of topologies of the transport network. The Pareto-optimal design versions subset including 3 topologies of the transport network was singled out in the criteria space of estimates of quality indices. The unique design version of the transport network topology was found when using the conditional criterion of preference based on minimizations of the scalar criterion function (6) at equal coefficients of importance of quality indices.

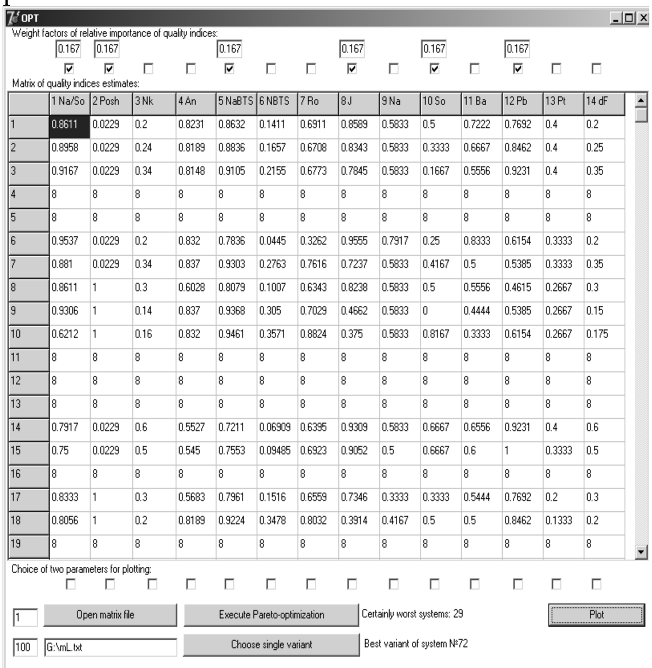
Multi-criteria choice of optimal design solutions in planning 4G NMC. The features of using multi-criteria optimization methods at planning the NMC radio network base on the LTE technology were considered [6]. By the results of the analysis of traffic in the network the calculation of the radio coverage was performed, the frequency parameters of the radio networks minimizing interference were selected, the parameters of the base stations (power, frequency, radiation patterns of antennas and their height of the suspension) were chosen**.** As a result of planning the values of the service area, levels of interference, load of traffic on the base stations, transmission rate, probability of errors etc. were obtained.

The following quality indices were specified in the process of the radio network optimization: availability of link, amount of bit errors, transmission rate on the line up, the latency, area of the radio coverage, network capacity, bandwidth, efficiency of radio spectrum use.

The Pareto-optimal design versions subset was singled out as a result of using the methodology of optimal design versions multi-criteria choice taking into account the given quality indices**.** In this case potentially accessible quality indices values representing multivariate potential characteristics and also multivariate diagrams of exchange of radio network quality indicators were obtained in the criteria space. The conditional criterion of preference based on the criterion function in the form of (7) was used for choosing the unique design version**.**

Program complex for multi-criteria choice of optimal design solutions. For a choice of optimal design solutions on the basis of multi-criteria optimization methods, there was developed the program complex [6]. It includes two parts solving the following issues: setting initial data and calculation of technical parameters for some permissible set of variants of NMC; a choice of Pareto-optimal network variants and narrowing them to a single one.

Fig. 2 shows, as an example, the program complex interface. There is a possibility to choose and set the quality indices values at the multi-criteria optimization of the concrete NMC. The information about the Pareto-optimal design versions, the values of the multivariate potential characteristics of the NMC being designed are highlighted on the screen. Here is shown part of table with values of 14 indices for 19 NMC variants. There is the possibility to choose («tick off») concrete quality indices to be taken into account at the multi-criteria optimization. Besides, here are given values of coefficients of relative importance of chosen quality indices. Moreover, there is a possibility to set a type of conditional criterion of preference and values of appropriate coefficients in the selected scalar criterion functions, which will be utilized for the unique preferable design version.



	1 Na/So	2 Posh	3 Nk	4 An	5 NaBTS	6 NBTS	7 Ro	8 J	9 Na	10 So	11 Ba	12 Pb	13 Pt	14 dF
1	0.8611	0.0229	0.2	0.8231	0.8632	0.1411	0.6911	0.8589	0.5833	0.5	0.7222	0.7692	0.4	0.2
2	0.8958	0.0229	0.24	0.8189	0.8836	0.1657	0.6708	0.8343	0.5833	0.3333	0.6667	0.8462	0.4	0.25
3	0.9167	0.0229	0.34	0.8148	0.9105	0.2155	0.6773	0.7845	0.5833	0.1667	0.5556	0.9231	0.4	0.35
4	8	8	8	8	8	8	8	8	8	8	8	8	8	8
5	8	8	8	8	8	8	8	8	8	8	8	8	8	8
6	0.9537	0.0229	0.2	0.832	0.7836	0.0445	0.3262	0.9555	0.7917	0.25	0.8333	0.6154	0.3333	0.2
7	0.881	0.0229	0.34	0.837	0.9303	0.2763	0.7616	0.7237	0.5833	0.4167	0.5	0.5385	0.3333	0.35
8	0.8611	1	0.3	0.6028	0.8079	0.1007	0.6343	0.8238	0.5833	0.5	0.5556	0.4615	0.2667	0.3
9	0.9306	1	0.14	0.837	0.9368	0.305	0.7029	0.4662	0.5833	0	0.4444	0.5385	0.2667	0.15
10	0.6212	1	0.16	0.832	0.9461	0.3571	0.8824	0.375	0.5833	0.8167	0.3333	0.6154	0.2667	0.175
11	8	8	8	8	8	8	8	8	8	8	8	8	8	8
12	8	8	8	8	8	8	8	8	8	8	8	8	8	8
13	8	8	8	8	8	8	8	8	8	8	8	8	8	8
14	0.7917	0.0229	0.6	0.5527	0.7211	0.06909	0.6395	0.9309	0.5833	0.6667	0.6556	0.9231	0.4	0.6
15	0.75	0.0229	0.5	0.545	0.7553	0.09485	0.6923	0.9052	0.5	0.6667	0.6	1	0.3333	0.5
16	8	8	8	8	8	8	8	8	8	8	8	8	8	8
17	0.8333	1	0.3	0.5683	0.7961	0.1516	0.6559	0.7346	0.3333	0.3333	0.5444	0.7692	0.2	0.3
18	0.8056	1	0.2	0.8189	0.9224	0.3478	0.8032	0.3914	0.4167	0.5	0.5	0.8462	0.1333	0.2
19	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Fig. 2. Program complex interface for multi-criteria choice of optimal design solutions

Conclusions

1. The methods of choosing the optimal design version of NMC are presented taking into account a totality of quality indices including selection of the Pareto-optimal solutions subset and its further contraction up to the unique design version.

2. Some examples of application of the considered methods of the multi-criteria choice of optimal design versions are given at solving various types of the NMC planning tasks.

3. The offered methods and appropriate program complex of multi-criteria choice of optimal design solutions enable to formalize registration of the NMC conflicting requirements and can be utilized in the available systems of the computer-aided planning of NMC.

References

1. Janusz Granat and Andrzej P. Wierzbicki. Multi-criteria analysis in telecommunications // Proceedings of the 37th Hawaii International Conference on System Sciences. - 2004. - P. 1-6.

2. UMTS Radio Network Planning, Optimization and QOS Management. For Practical Engineering Tasks / Edited by J. Lempidinen and M. Manninen. - Dordrecht: Kluwer Academic Publishers, 2004. - 343 p.

3. Mishra A.R. Advanced Cellular Network Planning and Optimization. 2G/2.5G/3G Evolution TO 4G. /Edited by Ajay R. Mishra. - UK: John Wiley and Sons Ltd, 2007. - 542 p.

4. Bezruk V.M., Bukhanko A.N., Chebotaryova D.V., Varich V.V. Multicriteria optimization in telecommunication networks planning, designing and controlling // Open Book “Telecommunications Networks”. Chapter 11. - Rijeka: INTECH, 2012. - P. 251 - 274.

5. Chebotaryova D.V., Bezruk V.M.. Multi-criteria Optimization of Design Solutions at Planning Honeycomb Networks of Mobile Link. - Kh.: CMIT, 2013. – 148 p.

6. Valeriy Bezruk, Daria Chebotaryeva, Minho Jo, Stanislav Ivanenko. Multi-Criteria Optimization in Planning of Mobile Communication Networks // MIKON 2014, 20th International Conference on Microwaves, Radar and Wireless Communications, June 16-18, Gdansk, Poland. P.633 - 639.

Received in final form April 23, 2014