Information and Telecommunication Sciences

INTERNATIONAL RESEARCH JOURNAL

ISSN 2312-4121

National Technical University of Ukraine
1898
KYIV POLYTECHNIC INSTITUTE

Volume 6 • Number 2(11) • July–December 2015

INFORMATION AND TELECOMMUNICATION SCIENCES
Volume 6 Number 2(11) July-December 2015
International Research Journal
Registration Certificate KB No 15064-3636P

Наказом Міністерства освіти і науки України від 25 квітня 2013 року №463
"Про затвердження рішень Атестаційної колегії Міністерства
щодо діяльності спеціалізованих вчених рад" журнал Information and Telecommunication Sciences
включено до Переліку наукових фахових видань України

According to the Ministry of Education and Science of Ukraine order № 463 on April 25, 2013
"On approval of the decisions of the Certifying Board of the Ministry
on the activities of the specialized scientific councils" Journal of Information and Telecommunication Sciences
was included to the List of academic editions of Ukraine

On the cover of the journal: *Single information platform. For detailed information, refer to page 25 of the paper "BUILDING PRINCIPLES OF THE NETWORK RESOURCES AND THE NETWORK SERVICES PLATFORM ARCHITECTURES"*

Founded in 2010

Printed in Ukraine

UDC 338.984:519.6

MULTICRITERIAL CHOICE OF TELECOMMUNICATIONS MEANS USING HIERARCHICAL ANALYSIS METHOD

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Background. Telecommunications means (systems, devices, technologies etc.) are important components of modern info-communications. The theoretical and practical aspects of choice of preferable version of telecommunication facilities are examined taking into account totality of quality indexes and judgments of experts on the basis of hierarchical analysis method.

Objective. The requirements of strict account of the inconsistent quality indices totality arise when choosing their design versions. This defines the necessity to use methods of multi-criteria optimization when choosing optimal design solutions from a set of admissible versions.

Methods. Scientific novelty of the work consists in the application of hierarchy analysis method for comparative analysis and selection of a preferred version of telecommunication means taking into account a set of quality indicators and judgments of experts. Solution of multicriteria optimization problems consists, in the general case, in the search of not one but some set of Pareto-optimal solutions which can be used at designing. Method based on attraction of some additional subjective information in the form of experts' judgments can be used for narrowing the Pareto set to the unique design solution.

Results. Theoretical and practical aspects of choosing the preferable version of telecommunications means taking into account the totality of quality indices and experts' judgments based on hierarchical analysis method are considered. Examples of the problems of choice of the preferred version for different types of telecommunication means, in particular, for digital communication systems with different modulation type, different versions for building a mobile network of the 3rd generation, different technologies of mobile networks of the 4th generation, different types of speech codecs are proposed.

Conclusions. Practical features are studied and recommendations are formulated for application of the method of hierarchy analysis in the selection of the preferred design versions of means of telecommunications.

Key words: telecommunications means; multicriteria optimization; Pareto-optimal solutions; choosing of preferred design version; hierarchical analysis method.

Introduction

Telecommunications means (systems, devices, technologies etc.) are important components of modern info-communications [1, 2]. The requirements of strict account of the inconsistent quality indices totality arise when choosing their design versions. This defines the necessity to use methods of multi-criteria optimization when choosing optimal design solutions from a set of admissible versions [2-4].

Solution of multi-criteria optimization problems consists, in the general case, in the search of not one but some set of Pareto-optimal solutions which can be used at designing [3, 4]. It is often required to choose the only preferable version of telecommunications means for further stages of info-communication systems creation. Various methods based on attraction of some additional subjective information in the form of experts' judgments can be used for narrowing the Pareto set to the unique design solution. As the comparative analysis of their efficiency shows [5] it is rationally to use for this purpose the hierarchies' analysis method (HAM) [6] in many practical situations.

Singularities of choice of the unique preferable version of telecommunications means with the HAM use are considered in this paper. Examples are given of the HAM application to the comparative analysis and choice of the preferable version for different types of telecommunications means taking into account the quality indices totality and experts' judgments.

Singularities of hierarchies' analysis method

The hierarchies' analysis method consists in decomposition of the problem of choice of the unique design version of some system into simple components and obtaining the judgments of experts on paired comparisons of various elements of the choice problem [6]. As a result of processing of the obtained numerical data of experts' judgments according to a certain mathematical procedure they receive components of the global vector the components of which characterize the priority of the choice of versions of the designed system and identify the choice of a single version of the system.

Decomposition involves structuring of the problem of choice in the form of the hierarchy of levels, which is the first stage of the HAM application. Fig. 1 presents in the most general form the hierarchy of the problem of choice, which is built from the top (goal selection) through the intermediate levels (indicators of quality) to the lowest level (the alternatives of building the system).

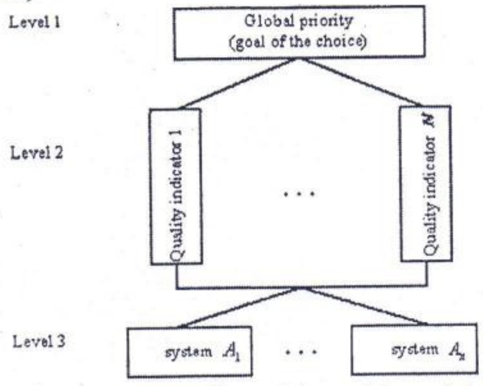

Fig. 1. Decomposition of the problem of choice in the levels hierarchy

The principle of comparative judgments of experts in the HAM consists in that the objects of the problem of choice are compared by experts in pairs by importance. The importance degree of different versions of the systems (level 3) and different quality indicators (level 2) are compared pairwise. The results of pairwise comparisons are reduced to the matrix form.

$$\begin{pmatrix} a_{11}a_{12}...a_{1j} \\ a_{21}a_{22}...a_{2j} \\ ... \\ a_{i1}a_{i2}...a_{ij} \end{pmatrix}. \quad (1)$$

Fig. 2. Matrix of pairwise comparisons of choice problem elements

Assessment of pairwise comparisons of elements a_{ij} is found using the subjective judgments of experts, numerically defined on a scale of relative importance of elements.

Then some processing of matrices of the hierarchies' elements pairwise comparisons is carried out at levels 2 and 3. From the mathematical point of view, the processing task is reduced to calculation of the main eigenvector, which, after a certain normalization becomes the vector of priorities of elements at the corresponding level of the hierarchy.

Components of the main eigenvector are calculated as a geometric mean value in the row of the matrix of pairwise comparisons of elements at each level

$$V_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}}, \quad i,j = \overline{1,n}. \quad (2)$$

Components of the elements priorities' vector are calculated through the components of the main eigenvector

$$P_i = \frac{V_i}{\sum_{i=1}^{n} V_i}, \quad j = \overline{1,n}. \quad (3)$$

Based on the matrix of quality indicators pairwise comparisons (1), obtained at level 2, components of the main eigenvector (2) and quality indicators priorities vector (3) of the system $\vec{P}$ are calculated. Similarly, there are evaluation matrices of pairwise comparisons of options systems at level 3 separately in relation to each quality indicator system. The components of the respective main eigenvectors and vectors of priorities $\vec{O}_i$, $i = \overline{1,n}$ are computed in relation to quality indicators on the basis of these matrices. The values of the global priorities vector components are computed using these data

$$C_j = \sum_{i=1}^{n} P_i Q_{ij}, \quad j = \overline{1,N}, \quad (4)$$

where n is the number of quality indicators, N is the number of the systems' versions being compared.

The most preferred version of the system is selected based on the maximum value of the global priorities vector components (4).

Consider the practical features of the HAM method use exemplified by the preferred version choice for different types of telecommunication means from some set of allowable versions taking into account the totality of quality indicators and judgments of experts [7].

Comparative analysis and selection of versions of construction for communication systems with different modulation types

Digital communication systems with coherent MPSK, and non-coherent MFSK with different number of modulation M positions with the probability of bit error $P_b = 10^{-5}$ [8] were chosen for the comparative analysis. Signal-to-noise ratio $K_1 = E_b/N_0$ and the efficiency of bandwidth utilization $K_2 = R/W$ are chosen as indicators of the quality.

It is assumed that, filtration by Nyquist (ideal rectangular) takes place prior to modulation, so a minimum of double the bandwidth at intermediate frequency is equal to $W_{IF} = 1/T$, where T is the symbol duration. In this case the effectiveness of the band use is $R/W = \log_2 M$. In MPSK modulation the value of R/W increases with the increase of M. It is assumed that the transmission band is equal to $W_{IF} = M/T$. In MFSK modulation the effectiveness of the use of the band is equal to $R/W = (\log_2 M)/M$. In this case the value of R/W decreases with the increase of M.

Table 1 presents the initial data for comparative analysis and selection of versions of communication systems with MPSK and MFSK with different number of positions *M*.

Table 1

Quality indicators	System's versions							
	1	2	3	4	5	6	7	8
	MPSK				MFSK			
	$M=2$	$M=4$	$M=8$	$M=16$	$M=2$	$M=4$	$M=8$	$M=16$
$K_1 = E_b/N_0$, bit/s/Hz	10	10	13	18	13	10	8	7
$K_2 = R/W$, dB	1	2	3	4	1/2	1/2	1/3	1/4

The original values of quality indicators K_1 and K_2 were normalized to the maximum value and converted to the comparable form. Then, taking into account the opinions of experts, the matrices of pairwise comparisons of these indicators of quality were formed, as well as different versions of the systems in relation to each quality indicator. With these matrices of pairwise comparisons the components of the main eigenvectors and the vectors of priorities were calculated according to (2), (3) and (4) using the special software complex created in the EXCEL environment.

Table 2 presents the calculated estimates of the main eigenvector component and the component of the vector of priorities of quality indicators.

Table 2

	K_1	K_2	V_i	P_i
K_1	1	1/2	0,707	0,333
K_2	2	1	1,414	0,667

Table 3 (first two columns) presents the calculated values of components of the vector of priorities of modulation versions in the communication system in relation to quality indicators. Here in the last line, the components of the vector of priorities of quality indicators are presented. The components of the vector of global priorities $\vec{C}$ are shown in the last column of table 3.

Table 3

System's version	P_1	P_2	C_j
1	0,117	0,078	0,09087
2	0,098	0,179	0,15227
3	0,045	0,25	0,18235
4	0,021	0,366	0,25215
5	0,038	0,049	0,04537
6	0,082	0,042	0,0552
7	0,214	0,02	0,08402
8	0,384	0,015	0,13677
P_i	0,33	0,67	

The preferred option №4 is selected by the maximum value of components of the global priorities vector $\vec{C}$ in the considered set of modulations' versions in the digital communication system. It corresponds to the communication system with coherent MPSK with the number of positions M=16, at signal/noise ratio E_b/N_0 =18 dB and efficiency of bandwidth utilization R/W = 4 bit/s/Hz.

Comparative analysis and selection of variants of construction of cellular networks of mobile communication of the 3rd generation

When carrying out a comparative analysis of the versions for building of cellular networks of mobile communication (NMC) of the UMTS standard the following network parameters are selected:

blocking probability $P_{бл}$, the density of subscribers served N_a/S_0 (N_a is the number of subscribers served, S_0 is the area of the served territory), the required number of base stations in the network is N_{BTS}. These parameters characterize the quality of the network operation and can be used as indicators of the network quality K_i. Table 4 shows the original data for $P_{бл}$ and the calculated parameters N_a/S_0 and N_{BTS} [4].

Table 4

Version of CMC	$K_1 = P_{бл}$	$K_2 = N_a/S_0$	$K_3 = N_{BTS}$
1	0,1	166	11
2	0,07	192	21
3	0,04	142	15
4	0,02	183	18
5	0,02	189	22

Table. 5 shows the matrix of pairwise comparisons of quality indicators and the calculated evaluations of components of the main eigenvector and the vector of priorities of the NMC quality indicators.

Table 5

	K_1	K_2	K_3	V_i	P_i
K_1	1	5	3	2,464	0,6173
K_2	1/5	1	1/5	0,3424	0,0858
K_3	1/3	5	1	1,1854	0,297

The calculated values of the components of the vector of the systems' versions priorities in relation to quality indicators, as well as components of the vector of global priorities $\vec{C}$ are shown in table. 6.

Table 6

Version of NMC	P_1	P_2	P_3	C_j
N_1	0,03	0,07	0,51	0,1779
N_2	0,04	0,45	0,07	0,0863
N_3	0,11	0,04	0,26	0,1498
N_4	0,47	0,16	0,12	0,3418
N_5	0,35	0,29	0,04	0,2551
P_i	0,62	0,09	0,3	

The maximum value of the components of the vector $\vec{C}$ corresponds to the NMC preferred version (№4), which is characterized by the minimum probability of blocking $P_{бл}$ = 0,02, density of the subscribers served N_a/S_0 = 183 subscribers/km^2 and the number of base stations N_{BTS} =18.

Comparative analysis and selection of technologies for mobile communications HSPA, WiMAX и LTE

Wireless technologies of mobile communication HSPA (release 7 and release 8), WiMAX and LTE [9-11] were chosen for the comparative analysis.. Table 7 presents the initial values of indicators of quality of different standards of cellular communication networks: K_1 - spectral efficiency (channel down), K_2 - radius of action, K_3 - speed of data transmission.

Table 7

Quality indicators	HSPA		WiMAX	LTE
	Release 7	Release 8	Release 1.5	
Version	1	2	3	4
-Spectral efficiency (down channel, MIMO 2×2), bits/Hz/s	0,87	1,75	1,59	1,57
Radius of action, km	30	40	50	5
Speed Mbps	21	35	48	75

The pairwise comparisons matrices of these quality indicators and versions of technologies in relation to quality indicators were formed for the considered technologies based on experts' judgments. Table 8 shows the calculated components of the main eigenvector of quality indicators and the components of the vector of quality indicators priorities.

Table 8

	K_1	K_2	K_3	V_i	P_i
K_1	1	3	1/3	1	0,2584
K_2	1/3	1	1/5	0,4058	0,1049
K_3	3	5	1	2,464	0,6367

The calculated values of the components of the vector of the technology versions priorities against each quality indicator, as well as components of the vector of global priorities are shown in table 9.

Table 9

Version	P_1	P_2	P_3	C_j
1	0,057	0,13	0,043	0,0553
2	0,494	0,279	0,093	0,2158
3	0,285	0,548	0,359	0,3586
4	0,165	0,043	0,505	0,3704
P_i	0,26	0,1	0,64	

The maximum value of component of vector of global priorities $\vec{C}$ corresponds to the preferred version of the mobile technology - №4. This is the LTE technology with the data transfer speed of 75 Mbit/s, spectral efficiency of 1.57 bit/Hz/s and radius of action of 5 km.

Comparative analysis and selection of speech codecs for networks of IP telephony

In the method of analytic hierarchy, when solving the problem of selection of the preferred design version, it is checked the consistency of experts' judgments by calculating the consistency index value and comparing it with some valid values. In this case the use of HAM with not a large number of compared alternatives is recommended.

This paper presents the features of the preferred version choice, when the Pareto-optimization stage is introduced previously to reduce the number of compared versions of the systems. The subset of Pareto-optimal versions is singled out and certainly worse versions are excluded. Next, the choice of the preferred design version is carried out in the obtained Pareto set using the method of hierarchies' analysis.

An example of analysis and selection of the preferred version from a set which includes 23 standard speech codecs used in the IP-telephony network design [12] is considered. The main technical characteristics of voice codecs, characterizing their consumer properties, in particular, the speed of encoding, the speech quality assessment, the complexity of implementation, the frame size, the total delay are chosen as quality indicators. It is easy to see that these indicators of quality are linked between themselves and they are of a competing nature.

The Pareto subset, which includes 12 versions of codecs, is singled out from the original set of 23 versions of speech codecs, taking into account the totality of 5 quality indicators. Next the pairwise comparison of Pareto-optimum versions of speech codecs is performed with respect to the chosen quality indicators. The corresponding eigenvectors and the vectors of versions' priorities in relation to the quality indicators $P_{ij}, j = \overline{1,12}$ are computed as a result of processing the obtained matrices of pairwise comparisons. They are given as columns in table. 10.

This table also shows the previously obtained components of the vector of quality indicators priorities $\vec{P}$. Using these data the values of the priorities global vector, presented in the last column of table 10, are computed.

Table 10

Version	Codec type	Components of vectors of speech codecs priorities against quality indicators P_{ij}, $j=\overline{1,12}$					Components of vector $\vec{C}$
		P_{1j}	P_{2j}	P_{3j}	P_{4j}	P_{5j}	
1	G 721	0,26	0,13	0,25	0,02	0,21	0,2
2	G 722a	0,02	0,24	0,09	0,01	0,09	0,09
3	G 722b	0,01	0,15	0,11	0,01	0,09	0,07
4	G 723.1a	0,03	0,01	0,05	0,23	0,01	0,04
5	G 723.1	0,04	0,03	0,04	0,26	0,01	0,05
6	G 726b	0,02	0,02	0,21	0,02	0,15	0,06
7	G 728	0,22	0,05	0,01	0,04	0,17	0,13
8	G 729	0,06	0,08	0,02	0,11	0,05	0,06
9	G 729a	0,06	0,03	0,17	0,09	0,02	0,07
10	G 729ea	0,01	0,09	0,01	0,08	0,04	0,08
11	G 728a	0,12	0,11	0,04	0,03	0,12	0,1
12	G 729d	0,05	0,06	0,02	0,1	0,04	0,05
$P_i, i=\overline{1,5}$		0,47	0,27	0,15	0,07	0,04	

The preferred speech codec is chosen by the maximum value of the computed components of the vector of global priorities. Such is the speech codec G. 721, which is characterized by the following quality indicators: encoding rate - 32 kbit/s, the speech encoding quality - 4.1, the complexity of the implementation - 7.2 MIPS, the frame size - 0.125 ms, the total delay - 30 ms.

Conclusions

Scientific novelty of work consists in the application of hierarchy analysis method for comparative analysis and selection of a preferred version for telecommunications taking into account a set of indicators of quality and judgments of experts. Examples of the problems of choice of the preferred version for different types of telecommunication means, in particular, for digital communication systems with different modulation type, different versions for building a mobile network of the 3rd generation, different technologies of mobile networks of the 4th generation, different types of speech codecs. Practical features are studied and recommendations are formulated for application of the method of hierarchy analysis in the selection of the preferred design versions of means of telecommunications.

References

1. Semenov Yu. V. Design of next generation of communication networks. – SPb.: BHV-Petersburg, 2005. – 236p.

2. Bezruk V. M., Bukhanko A. N., Chebotaryova D. V. Optimal decision making in info-telecommunications taking into account the totality of quality indices // In the monograph "Science-intensive technologies in info-telecommunications: information processing and protection". – Kharkiv: SMITH Company, 2013. – P. 104 – 125.

3. Noguin V. D. Decision-making in multicriteria environment: quantitative approach. – M.: FIZMATLIT, 2002. – 176p.

4. Chebotaryova D. V., Bezruk V. M. Multicriterion optimization of the design decisions when planning of cellular mobile communication networks. – Kharkiv: SMITH Company, 2013. – 148p.

5. Bezruk V. M., Ponomarenko N. N. , Skorik Y. V. Analysis of effectiveness of methods of multi-criteria selection of preferred version for telecommunications // Telecommunications Problems. – 2015. – № 1 (16). – P. 42 - 53.

6. Saaty T. L. The Analytic Hierarchy Process, New York: McGraw Hill. – 1980. – 278 p.

7. Bezruk V. M., Skorik Y. V. Application of the analytic hierarchy process in the choice of means of telecommunication taking into account the totality of quality indices // Radioelektronika i informatika. – Kharkiv: KNURE. – 2013. – P. 24 – 29.

8. Sklar B. Digital communication. The theoretical basis and practical application: TRANS. Engl. – M.: Publishing house "Williams", 2003. – 1104p.

9. Berlin A. N. Digital cellular telecommunications system. – M.: Eco-Trends, 2007. – 230p.

10. Holma H., Toskala A. LTE for UMTS-OFDMA and SC-FDMA based radio access. – Finland .John Wiley's Sons, Ltd. 2009. – 433p.

11. Vishnevskiy V., Portnoy S., Shahnovich I. Encyclopedia of WiMAX. The path to 4G. - Technosphere, 2009. – 472p.

12. Bezruk V. M., Skorik Yu. V, Chebotarev D. V. Methods of multicriteria optimization in the choice of speech codecs, considering the totality of quality indices // Telecommunications Problems. – 2013. – № 3 (12). – P. 27 – 35.

Received in final form on November 11, 2015

Безрук В. М., Скорик Ю.В.

Багатокритеріальний вибір засобів телекомунікацій з використанням методу аналізу ієрархій.

Проблематика. Засоби телекомунікації (системи, прилади, технології та інш.) є важливими компонентами сучасних інфокомунікацій. Розглядаються теоретичні і практичні аспекти вибору переважного варіанту засобів телекомунікацій з урахуванням сукупності показників якості і суджень експертів на основі методу аналізу ієрархій.

Мета. Вимоги строгого врахування суперечливих показників якості виникають при виборі переважного проектного варіанту засобів телекомунікацій. Це обумовлює використання методів багатокритеріальної оптимізації при виборі оптимальних проектних рішень із множини допустимих варіантів.

Методи. Наукова новизна роботи полягає в застосуванні методу аналізу ієрархій для порівняльного аналізу і вибору переважного варіанту засобів телекомунікацій з урахуванням сукупності показників якості і суджень експертів. Рішення багатокритеріальних задач оптимізації полягає, у загальному випадку, у пошуках не одного, а деякої множини Парето-оптимальних варіантів, які можуть бути використані при проектуванні. Для звуження множини Парето до єдиного проектного варіанту можна використати метод, заснований на отриманні та обробці додаткової суб'єктивної інформації у вигляді суджень експертів.

Результати. Розглянуто теоретичні та практичні аспекти вибору переважного варіанту засобів телекомунікацій з урахуванням сукупності показників якості і суджень експертів, що засновані на методі аналізу ієрархій. Наведено приклади вирішення задач вибору переважного варіанту для різних типів засобів телекомунікацій, зокрема, для цифрових систем зв'язку з різним типом модуляції, різних варіантів побудови мережі мобільного зв'язку 3-го покоління, різних технологій мережі мобільного зв'язку 4-го покоління, різних типів мовних кодеків.

Висновки. Досліджено практичні особливості і сформульовані рекомендації щодо застосування методу аналізу ієрархій для вибору переважних варіантів побудови засобів телекомунікацій.

Ключові слова: засоби телекомунікації; багатокритеріальна оптимізація; Парето-оптимальні рішення; вибір переважного проектного варіанту; метод аналізу ієрархій.

Безрук В. М., Скорик Ю.В.

Многокритериальный выбор средств телекоммуникаций с использованием метода анализа иерархий

Проблематика. Средства телекоммуникаций (системы, приборы, технологии и др.) являются важными компонентами современных инфокоммуникаций. Рассматриваются теоретические и практические аспекты выбора предпочтительного варианта средств телекоммуникаций с учетом совокупности показателей качества и суждений экспертов на основе метода анализа иерархий.

Цель. Требования строгого учета противоречивых показателей качества возникают при выборе предпочтительного варианта средств телекоммуникаций. Это определяет необходимость использования методов многокритериальной оптимизации при выборе оптимальных проектных решений из множества допустимых вариантов.

Методы. Научная новизна работы заключается в применении метода анализа иерархий для сравнительного анализа и выбора предпочтительного варианта средств телекоммуникаций с учетом совокупности показателей качества и суждений экспертов. Решение многокритериальных задач оптимизации состоит, в общем случае, в поисках не одного, а некоторого множества Парето-оптимальных вариантов, которые могут быть использованы при проектировании. Для сужения множества Парето до единственного проектного варианта может быть использован метод, основанный на получении и обработке дополнительной субъективной информации в виде суждений экспертов.

Результаты. Рассмотрены теоретические и практические аспекты выбора предпочтительного варианта средств телекоммуникаций, с учетом совокупности показателей качества и суждений экспертов, которые основаны на методе анализа иерархий. Приведены примеры решения задач выбора предпочтительного варианта для различных типов средств телекоммуникаций, в частности, для цифровых систем связи с разным типом модуляции, различных вариантов построения сети мобильной связи 3-го поколения, различных технологий сети мобильной связи 4-го поколения, различных типов речевых кодеков.

Выводы. Исследованы практические особенности и сформулированы рекомендации по применению метода анализа иерархий для выбора предпочтительных вариантов построения средств телекоммуникаций.

Ключевые слова: средства телекоммуникаций; многокритериальная оптимизация; Парето-оптимальные решения; выбор предпочтительного проектного варианта; метод анализа иерархий.