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Analysis of Voice over IP Networks Service Quality Parameters Information

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Introduction

Using data communications network for voice data transmission (VoIP – Voice over IP) it is very important that this service could be able to compete with traditional voice telephony, when. This is achieved when customer in VoIP telephone handset hears sound of not worse quality than in case of PSTN network. The abundance of scientific works and projects only demonstrates the relevance of this problem [1, 2].

The new requirements for services quality force us to observe continually more and more qualitative characteristics today. Size of the set of these characteristics depends on the specific technology application. It is purposeful to optimize service quality assessment process, by extracting significant attributes, i.e. information, universal parameters that best reflect changes of service quality, referring to which states of provided service quality are differentiated – e.g. good, nominal, bad. This is problem of states norms formation of telecommunication networks efficiency according to the given quality criterion. Current generation SNMP agents only transfer accumulated statistical data to the network control station without their analysis [3]. Having selected and processed only essential quality indicators the amount of network control information transferred by communication channels is reduced, when sending it to the control center.

However, in case of large volume of training realization set, this task is much impeded. In addition, some classes of different network efficiency states, made out of normal values of individual network efficiency quality indicators, overlap, process of quality state determination complicates [4, 5].

Thus, goal of state description optimization is minimization of efficiency data of telecommunication network and its elements, reducing them to optimal subspace from their general n – dimensional space. It is purposeful to take into account their statistical dependence and current correlation, by making optimal multidimensional vectors-factors of their states norms.

In Fig. 1 the structural scheme of VoIP service quality assessment is given.

Authors limit themselves to evaluation of information assessment for VoIP service quality indicators, without analyzing cluster analysis and data classification methods.

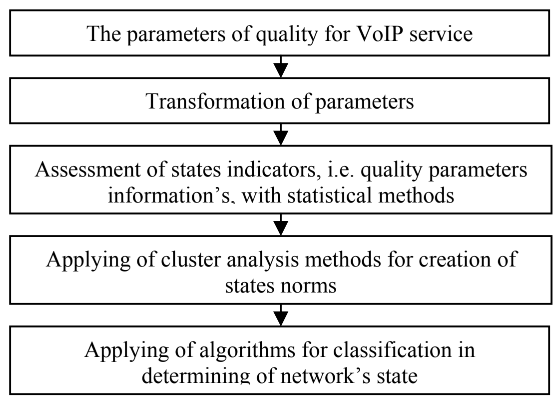

Fig. 1. Structural scheme of analytical model for VoIP service quality state assessment [6], [7]

Determination of information's by using factor analysis

Usually factor analysis is found in biomedicine, psychology and economics [8], [9], [10], [11]. We can compactly and fully describe analyzed object, distinguish variable and dependent features from independent, to combine them by using moderate amount of combined factors – condensed indicators using it. They reflect internal, objectively existing regularities, which can be unwatched immediately. Factor analysis is multidimensional branch of the statistical analysis, analyzing internal structure of variance-covariance matrixes. It refers to results of actual, changing features watching, allows determining essential factors, and does not demand forward assumptions with respect of analyzed information. Model of factor analysis can be expressed by the equation [8]:

$$y_j = \sum_{i=1}^{m} a_{ji} f_i + a_j u_j; \quad \left(j = \overline{1,n}\right), (m < n); \tag{1}$$

where n – indicators' number; m – factors' number; y_j - analyzed j indicator; f_i - i general factor; u_j - j indicator specific factor; a_{ji} - i general factor charge, falling on j indicator; a_j - specific factor charge.

General factors in model determine most part of dispersion of analyzed initial quality indicators, and specific factors express rest part of dispersion. Factor charge shows correlation between analyzed initial indicators and factor. The biggest this correlation, the indicator more influences defined factor [8].

One can see (1), that in order to express indicators through factors and their charges it is needed to:

- forecast number of factors, fully reflecting entirety of indicators;
- find factor charges.

Finding of factors' number and factor charges

Factors number N is calculated [8]:

$$N = \frac{2n + 1 - \sqrt{8n+1}}{2}, \tag{2}$$

where n – indicators' number, m – number of possible factors.

One of the most important and mostly applied factorization methods is *main factors method*. This method is based on making of specific equations system and its solving, by finding specific values and specific vectors meeting them. Received factor solution is factor charges of individual indicators, i.e. correlation coefficients, showing force of factors and initial indicators relation.

It is important to know mostly not only factor charges but also the factor values, thus factors analysis procedure can be extended, and factor values can be calculated by solving linear equations system (1) [9].

Dispersion in factor analysis model

The characteristic of indicator y_j is dispersion σ_j^2 in linear model of factors' analysis (1):

$$\sigma_j^2 = \frac{1}{N}\sum_{i=1}^{N} y_{ji}^2 = \frac{1}{N}[a_{j1}^2 \sum_{i=1}^{N} f_{1i}^2 + a_{j2}^2 \sum_{i=1}^{N} f_{2i}^2 + \ldots + a_{jm}^2 \sum_{i=1}^{N} f_{mi}^2 + a_j^2 \sum_{i=1}^{N} u_{ji}^2 +$$
$$+ 2(a_{j1}a_{j2}\sum_{i=1}^{N} f_{1i}f_{2i} + a_{j1}a_{j3}\sum_{i=1}^{N} f_{1i}f_{3i} + \ldots + a_{j(m-1)}a_{jm}\sum_{i=1}^{N} f_{(m-1)i}f_{mi} +$$
$$+ a_{jm}a_j \sum_{i=1}^{N} f_{mi}f_{ji})]. \tag{3}$$

Because general factors are normalized, random variable the equalities are valid:

$$\frac{1}{N}\sum_{i=1}^{N} f_{1i} f_{2i} = r_{f_1 f_2}, \tag{4}$$

$$a_{j1}^2 \frac{1}{N}\sum_{i=1}^{N} f_{11}^2 = a_{ji}^2, \tag{5}$$

$$a_{j1}a_{j2}\frac{1}{N}\sum_{i=1}^{N} f_{1i} f_{2i} = a_{j1}a_{j2} r_{f_1 f_2}. \tag{6}$$

In addition, it is assumed, that factors do not inter-correlate. Then we can write (3) as follows:

$$\sigma_j^2 = a_{j1}^2 + a_{j2}^2 + \ldots + a_{jm}^2 + a_j^2 = 1. \tag{7}$$

Equation (7) means full dispersion of indicator. It consists of general, specific and dispersion appeared due to errors. General dispersion, which is the main part of the full dispersion, is defined by general factors. Specific dispersion is determined by one or few typical factors, which are different for each indicator:

$$a_j^2 = 1 - h_j^2 - b_j^2; \tag{8}$$

where a_j^2 - part of dispersion defined by specific factor; h_j^2 – part of full dispersion determined by general factors:

$$h_j^2 = a_{j1}^2 + a_{j2}^2 + \ldots + a_{jm}^2. \tag{9}$$

Dispersion b_j^2, determined by errors, is random variable, appearing due to the errors occurred during watching and data processing. This part of dispersion is miserly and therefore during factors analysis the main attention is paid to general dispersion and general factors related with it. During the analysis the dispersion parts fallen to general factors are found, and this allows assessing factor weight for indicator [10].

Main factors method analysis

Goal of main factors, as well as all factors analysis methods is to receive factor charges matrix. We receive it from initial data matrix X , having made some actions:

$$X = \begin{Vmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{N1} & x_{N2} & \ldots & x_{Nn} \end{Vmatrix}, \tag{10}$$

where X - initial data matrix, n – technical indicators number, N – number of analyzed objects.

Sequence of the actions can be demonstrated by scheme (Fig. 2.):

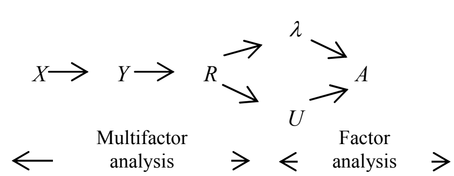

Fig. 2. Analysis of main factors

For indicators normalization at the first step matrix of the initial data X is normalized and centralized. Three stages are classified by calculating:

- arithmetic means of analyzed objects indicator, i.e. grouping centers:

$$\bar{x}_j = \frac{1}{N}\sum_{i=1}^{N} x_{ij}, \qquad (11)$$

where $\bar{x}_j$ - arithmetic mean of j indicator, x_{ij} - value of i object j indicator;

- standard deviation of each analyzed indicator:

$$S_j = \sqrt{S_j^2}; \qquad (12)$$

$$S_j^2 = \frac{1}{N}\sum_{i=1}^{N}\left(x_{ij} - \bar{x}_j\right)^2; \qquad (13)$$

where S_j - standard deviation of indicator; S_j^2 - dispersion, showing average scatter about grouping center; $\bar{x}_j$ arithmetic mean of j indicator; x_{ij} - value of I object j indicator;

- normalized and centralized values of analyzed indicators:

$$y_{ij} = \frac{x_{ij} - \bar{x}_j}{S_j}, \quad i = 1, \ldots, N, \qquad (14)$$

where y_{ij} - normalized j indicator value for i object, x_{ij} - basic value of i object of j indicator, $\bar{x}_j$ - arithmetic mean of j indicator.

The correlation matrix $\|r\|$ of indicators is made

$$R = \begin{Vmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{Vmatrix}; \qquad (15)$$

where r_{jk} - indicators j and k correlation coefficient, which is calculated:

$$r_{jk} = \frac{1}{N}\sum_{i=1}^{N} y_{ji} y_{ki}, \qquad (16)$$

where y_{ji} and y_{ki} - i object k and j indicators normalized values.

Received correlation matrix is as the basis for further calculation. Usually in factor analysis if correlation matrix consists of significant correlations, the question is asked: is here general factor *F1*, the influence of which having eliminated, correlations between individual indicators would become equal to zero? If, except *F1*, correlations are still not equal to zero or near zero, the same is made with the second factor, which is treated as orthogonal with respect to *F1*. This process is repeated until correlations between initial indicators become near to zero or equal to zero. Then we can say that entire general dispersion is explainable. This is principle of factor analysis [10], [11].

In method of main factors the factors are defined by solving the equation:

$$\left(A - \lambda E\right)x = 0 \qquad (17)$$

and finding matrix of own values $\|\lambda\|$:

$$\lambda = \begin{Vmatrix} \lambda_1 & 0 & \ldots & 0 \\ 0 & \lambda_2 & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & \lambda_n \end{Vmatrix}. \qquad (18)$$

Own vectors of matrix are found by solving system of linear equations, respectively:

$$\begin{cases} (a_{11} - \lambda)x_1 + a_{12}x_2 + \ldots + a_{1n}x_n = 0, \\ a_{21}x_1 + (a_{22} - \lambda)x_2 + \ldots + a_{2n}x_n = 0, \\ \ldots \\ a_{n1}x_1 + a_{n2}x_2 + \ldots + (a_{nn} - \lambda)x_n = 0. \end{cases} \qquad (19)$$

Matrix of own vectors $\|u\|$ are received:

$$U = \begin{Vmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ u_{n1} & u_{n2} & \cdots & u_{nn} \end{Vmatrix}. \qquad (20)$$

Many methods, e.g. Lagrange factors, Jakobi factors etc., are used for finding own values and own vectors. Method of main axes turn is the most convenient of them with respect to calculation costs [8].

Due to this methods evaluating information density we can determine constituents of multidimensional vectors consisting of quality indicators, significant for states distinguishing.

Practical part

The enterprise „X" data transfer channel between two cities (between enterprise subsidiaries) is used for measurement of network characteristics in actual network. There are telephone stations with VoIP interface in both cities. Packet delay between telephone stations is almost equal to packet delay from personal computer in one city enterprise network to internet network gateway of other city enterprise.

For measurement of packet delay the personal computer with Linux Debian operation system is used. Data are received by *sing* procedure, analogous to *ping* procedure (*sing* - *Send ICMP Nasty Garbage Packets to Network Hosts*). It is chosen due to the possibility to save measurement results in form of text file; also, the list of possibilities is extended, as, for example, Type Of Service mark definition and other. s*ing* procedure is adjusted to customer needs, it can be changed, whereas *ping* procedure is less flexible and adjustable [12]. *sing*, as *ping* procedure, sends ICMP (*Internet Control Message Protocol*) packets to network nodes and, having measured time from packet sending to response return, describes statistically the network delay (channel bandwidth is 512 kb/s and packet size is 128 bytes length).

By repeating such sending of ICMP series we can collect network efficiency statistics for various time periods. Received values of delay show per what time sent ICMP packet returns. To find time of packet transfer via network in one direction we must received round-trip delay values divide by two. *sing* procedure results also show packet loss statistics. This characteristic is assessed in percent; its value is equal to lost (non-returned) ICMP packets amount ration to 100 packets sent to network.

For calculation of delay fluctuation J the classic standard deviation formula (13) is used. In this case delay fluctuation J:

$$J = \sqrt{\frac{\sum_{i=1}^{n}(t_i - \bar{t})^2}{n}}, \qquad (21)$$

where t_i – time between i packet sending and its return (ms), $\bar{t}$ - average packet sample delays (ms), n – number of packets in sample, J – delay fluctuation (ms).

Data of communication channel load are taken from statistic data of the analyzed network branch collected in internal database. It is realized with the program packet MRTG, by collecting data from SNMP (Simple Networks Management Protocol) agents installed in routers [13].

Having calculated service quality indicators values, we go to the next stage - factor analysis application for analysis of these characteristics. This process consists of three stages:

- statistical data set selection;
- reduced correlation matrix;
- own vector search.

Statistical data selection

First, from statistical data, collected during measuring experiment, matrixes of initial data of 4 columns of 20 rows are formed: of 4 indicators of 20 measurement samples in each (e.g. in table 1).

Calculations are made with *Mathcad* application. Results are provided having made averaging of 20 matrixes quality parameters values. In matrix columns the values of round-trip delay (ms), delay fluctuation (ms), channel load (Mb/s) and packets loss (%) are set.

It is necessary to eliminate dimension of initial data matrix elements (14) (Table 1).

Reduced correlation matrix

Next step is correlation matrix designing, in order to determine indicators interrelation.

Table 1. Data matrixes

Example of initial data ***Normalized data***

$$x_{j,k} = \begin{pmatrix} 50.6 & 37.432 & 0.5 & 6 \\ 41.4 & 22.615 & 0.43 & 2 \\ 36.1 & 24.036 & 0.36 & 0 \\ 28.4 & 19.37 & 0.24 & 1 \\ 31.5 & 23.008 & 0.19 & 0 \\ 34.1 & 33.27 & 0.33 & 2 \\ 31.2 & 24.4 & 0.2 & 0 \\ 24.7 & 18.494 & 0.15 & 0 \\ 32.8 & 24.331 & 0.25 & 2 \\ 36.5 & 30.566 & 0.4 & 6 \\ 41 & 29.309 & 0.47 & 5 \\ 35.6 & 26.375 & 0.28 & 0 \\ 51.6 & 36.359 & 0.5 & 3 \\ 46.6 & 33.666 & 0.4 & 1 \\ 34.6 & 24.137 & 0.35 & 0 \\ 30.1 & 21.914 & 0.21 & 0 \\ 29.3 & 20.002 & 0.2 & 0 \\ 27 & 23.317 & 0.18 & 1 \\ 29 & 20.606 & 0.2 & 2 \\ 24.1 & 17.135 & 0.15 & 0 \end{pmatrix} \qquad y_{i,j} = \begin{pmatrix} 2.05 & 2.05 & 1.73 & 2.27 \\ 0.85 & -0.5 & 1.12 & 0.23 \\ 0.17 & -0.25 & 0.52 & -0.79 \\ -0.83 & -1.06 & -0.51 & -0.28 \\ -0.43 & -0.43 & -0.94 & -0.79 \\ -0.09 & 1.33 & 0.26 & 0.23 \\ -0.47 & -0.19 & -0.86 & -0.79 \\ -1.31 & -1.21 & -1.29 & -0.79 \\ -0.26 & -0.20 & -0.43 & 0.23 \\ 0.22 & 0.87 & 0.87 & 2.27 \\ 0.8 & 0.65 & 1.47 & 1.76 \\ 0.1 & 0.15 & -0.17 & -0.79 \\ 2.18 & 1.86 & 1.73 & 0.74 \\ 1.53 & 1.4 & 0.87 & -0.28 \\ -0.03 & -0.24 & 0.44 & -0.79 \\ -0.61 & -0.62 & -0.77 & -0.79 \\ -0.71 & -0.95 & -0.86 & -0.79 \\ -1.01 & -0.38 & -1.03 & -0.28 \\ -0.75 & -0.84 & -0.86 & 0.23 \\ -1.39 & -1.44 & -1.29 & -0.79 \end{pmatrix}$$

Correlation matrix made is symmetrical. In main its diagonal are figures of one. This shows the maximal interrelation of the indicators:

$$r_{j,k} = \frac{1}{n}\sum_{i=0}^{n-1}\left(y_{i,j} \cdot y_{i,k}\right). \qquad (22)$$

The reduced correlation matrix is made; main diagonal are not figures of one in it's, but values of relevant indicators commonalities. Indicators commonalities matrix is find with the first *centroid* factor method [8], [9]. The maximal correlation values of relevant indicators are written into main diagonal, and then quadrate of sum of relevant column members is divided by total matrix elements sum (23).

$$h_{j,j} = \frac{\left(\sum_{k=0}^{m-1} r_{Ij,k}\right)^2}{\sum_{k=0}^{m-1}\sum_{l=0}^{m-1} r_{Ik,l}}. \qquad (23)$$

The reduced correlation matrix R' is received, necessary for calculation of own vector – factor equation, having placed received commonalities values into main diagonal of indicators correlations matrix $\|r\|$.

Own vector search

Mentioned method [8, 9] refers to iterative procedure, with which the main axes are selected, simultaneously the distinctive roots of equation and coefficient along the relevant factor are found. Roots are found according to their size descending; this method is treated as effective for tasks for which is enough to find a little amount of factors, having the largest own values and their coefficients (indicators information density) therefore.

Iteration process starts by selection of indicators' number m. Later they are reorganized by correlation coefficients multiplication products, until they coincide with searched factor charges. This operation in further calculations marked as $R^{'} \cdot q_I$ is vector $q_I = \{\alpha_{I1}, \alpha_{I2}, \ldots, \alpha_{\mathrm{Im}}\}$ reorganization into new vector. Geometrically this corresponds to straight line turn in new direction, the cosines of which become proportional to vector $R^{'} \cdot q_I$ elements. When straight line is turned in needed angle, new vector is proportional to previous. Invariant straight lines become searched main axes. Thus, the following stages are distinguished.

1. Having full matrix of factor charges $\|a\|$, the most significant factors are determined and final matrix of charges is formed. Quantity of factors is calculated according to (2).
2. The matrix's $R^{'}$ rows sums M (24) are calculated and divided by maximal sum. In such way the first approximation vector α_I (25) is received. Values of this and further approximation vectors are not directly used for own vector calculation, but according to them it is defined whether matrix is raised to the needed power (i.e. are the axes turned in required angle).

$$M_j = \sum_{i=0}^{m-1} R^{'}_{i,j}\,, \tag{24}$$

$$\alpha_{I\,j} = \frac{M_j}{\max(M)}\,. \tag{25}$$

3. Having multiplied relevant columns of matrix $R^{'}$ by sum matrix M (24), received values T_{II} are used for finding of the second approximation vector:

$$T_{II\,j} = \sum_{i=0}^{m-1} R^{'}_{i,j} \cdot M_i\,. \tag{26}$$

4. The second level matrix approximation is calculated:

$$\alpha_{II\,j} = \frac{T_{II\,j}}{\max(T_{II})}\,. \tag{27}$$

5. Values of the second degree approximation are compared with the first approximation values. The same is made with the fourth degree approximation (it is compared with the second) and so on. To find the fourth degree approximation matrix $R^{'}$ is squared and the sums of received matrix columns are calculated again. The eight degree approximation by 1% precision corresponds the fourth degree approximation, so we can say, that values do not change further and are proportional to the own vector constituents. These received values are multiplied by matrix $R^{'}$ later. Received elements $R^{'} \cdot q_I$ are divided again by the maximal their value. Received results are marked α_I again for simplicity. Having multiplied reduced correlation matrix $R^{'}$ by the last approximation vector, the vector, proportional to own vector, is received:

$$R^{'} \cdot q_I = R \cdot \alpha_{VIII}\,. \tag{28}$$

When approximation will become equal or will be near enough, this will mean, that matrix is to the needed power, and vector of the multiplication product $R^{'} \cdot q_I$ will be parallel to searched own vector. Vector $R^{'} \cdot q_I$ maximal member $R^{'} \cdot q_{I\max}$ is the first root of the typical equation λ=1,322.

6. The factor charges a are find. Whereas, having four initial indicators, the optimal number of factors is one (2), received factor charges correspond to indicators information density:

$$a_j = \frac{\alpha_{I\,j} \cdot \sqrt{\lambda}}{\sqrt{\sum_{i=0}^{m-1} \left[(\alpha_{I\,i})^2\right]}}\,. \tag{29}$$

Referring to empirical data, having calculated factor charges, the equation of main factor is written:

$$F = 0.933 \cdot D + 0.905 \cdot J + 0.950 \cdot A + 0.737 \cdot L, \tag{30}$$

where F – main factor, D – delay, J – delay fluctuation, A – channel workload, L – packets loss.

Note: In expression (30) values of the indicators are normalized.

Conclusions

To reduce state classification errors it is purposeful to optimize not only classification process, but the states classes' formation - clustering, having analyzed efficiency features characterizing states, i.e. carried out quality indicators information density analysis. The factors analysis method is chosen to assess indicators information density, because it is unlimited in the input parameters quantity.

Statistical data of four service qualitative indicators (packets delay, delay fluctuation, channel load and packets loss) are collected. Having used main factors method it was defined that the most impact on the rest characteristics and also to entire system has the channel load. Its weight or correlation with the defined factor is 0.95. This means that the channel load values provide the essential information about the system work. Next according to the information density in the main factor is the packet delay – 0.933. Packet loss indicator information density is much less than other factors – about 0.737. This can be explained by the fact that under nominal network functioning conditions the little losses of the packets are fixed (during the experiment measuring by 100 ICMP packets by 15 min, mostly they were not lost).

Having applied way of the features information density assessment, described in the paper for the service quality states determination in data transfer network, we can minimize possibility of VoIP service quality mistaken assessment. In practice it is realized by installing into network servers and routers intellectual SNMP agents, analyzing information accumulated in the network element.

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R. Jankūnienė, R. Slanys, A. Budnikas, L. Gudonavičius. Balso perdavimo paslaugos IP tinklais kokybės parametrų informatyvumo tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 7(63). – P. 16–21.

Nagrinėjamas faktorinės analizės taikymas kokybės parametrų informatyvumui tirti, teikiant balso perdavimo IP tinklais paslaugą, kad sumažėtų ryšio kanalais perduodamos tinklo valdymo informacijos kiekis. Pasiūlyta taikyti pagrindinių faktorių metodą, kuris taikytinas, nes tai patogu esant neribotam kokybės parametrų skaičiui. Remiantis empiriniais VoIP paslaugos parametrais nustatyta, kad didžiausią įtaką visos sistemos darbo kokybei turi paketų vėlinimas ir kanalo apkrautumas.

Pritaikius šį metodą, galima minimizuoti VoIP paslaugos kokybės būsenos klaidingo klasifikavimo tikimybę. Il. 2, bibl. 13 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

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Actual questions for reducing amount of management information, transmitted over communications lines, are analyzed, i.e. an applying of factor analysis in examination of informative quality parameters for voice data transferring over IP. It was proposed to use main factors method, because it is unlimited in the input parameters quantity. It was defined from the using of empirical VoIP service data, that the most impact to the quality for functioning of all system has the parameters of packet delay and channel load.

The possibility of VoIP service quality mistaken assessment for the service quality states determination can be minimized, having applied this method. Ill. 2, bibl. 13 (in English; summaries in Lithuanian, English and Russian).

Р. Янкунене, Р. Сланис, А. Будникас, Л. Гудонавичюс. Исследование информативности параметров качества для передачи голоса через IP // Электроника и электротехника. – Каунас: Технология, 2005. – № 7(63). – С. 16–21.

Анализируются актуальные вопросы использования факторного анализа для исследования информативности параметров качества для сервиса передачи голоса через IP (VoIP), чтобы уменьшить объем передаваемой информации управления по каналам связи. Авторами предложен метод по использованию основных факторов, который удобный при безграничном числе параметров качества. Из эксперимента установлено, что основное влияние на работу всей системы имеет задержка пакетов и нагрузка канала.

Использование этого метода дает возможность минимизировать вероятность ложного определения состояния качества VoIP сервиса. Ил. 2, библ. 13 (на английском языке; рефераты на литовском английском и русском яз.).