UDC 621.391

QUALITY CONTROL OF FUNCTIONING OF TELECOMMUNICATION SYSTEMS

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Abstract *- Quality control of functioning of telecommunication systems (TCS) is considered, based on the results of the statistical analysis of the spectral matrix of residual detunes obtained at the optimal state estimation of the different elements in the network. The recommendations are given on the method of forming the matrix of residual detunes. (50) The proposed method of diagnosing the quality of telecommunications systems solved in the space of signals on the principle of "learning with a teacher" has a higher reliability than the method solved in the parameter space. The residual detune, obtained due to result of best estimation system as a result of a "supervised learning", has the most complete information about the state of the system deviation from the desired characteristics. Therefore, the method based on the use of the statistical characteristics of the sequence of residual detunes (the matrix of residual detunes) to diagnose the quality of functioning of TCS is the most informative. The upper confidence limit of the spectral norm of the matrix normalized for residual detunes can be used as a threshold function for detecting disorders (disorder) in the state of the system. In order to localize the causes of disorder it may be recommend to use of individual assessment of filters for each object of diagnosis.*

Анотація *– Розглядається метод контролю якості функціонування телекомунікаційних систем, заснований на результатах статистичного аналізу спектральної матриці нев'язок, одержуваних при оптимальній оцінці стану в різних елементах мережі. Даються рекомендації по методу формування матриці нев'язок.*

Аннотация *– Рассматривается метод контроля качества функционирования телекоммуникационных систем, основанный на результатах статистического анализа спектральной матрицы невязок, получаемых при оптимальной оценке состояния в различных элементах сети. Даются рекомендации по методу формирования матрицы невязок.*

Introduction

Quality control of telecommunications systems (TCS) determines the success of the business of service providing.

You can specify multiple profiles to assess the quality of the TCS functioning. We point out two main ones:

– the quality of the functional characteristics for the hardware of next generation networks (NGN);

– quality of Service (QoS) for users in the operation.

A number of known criteria [1 - 3], which must meet specified quality characteristics, has been developed. To check compliance with the criteria different methods of diagnosis are used. It is known that the problem of diagnosis in the operation of TCS can be addressed to either space parameters or in the signal space.

Diagnosis in the parameter space is usually limited to the evaluation of the measured values of the parameters of the diagnosis object and comparison of the estimates with nominal values.

Another method of diagnosis in the space of signals is based on the testing of the corresponding diagnosing object by reference signals [4 - 6]. Usually, the diagnosis of the network state testing is "end-to-end" or "from node to node." In the evaluation process adopted by the test signals we can get the appropriate residuals containing information about any mode deviation of test objects or worsening functional characteristics. Thus, there is the task of analyzing the statistical characteristics of the current values of the residuals and use the data to diagnose the quality of the network.

Using the terminology of learning systems, the first of these methods can be called the training "without a teacher", the second - the learning "with a teacher", where the teacher uses test signals specially formed and transmitted over the network.

I. Method description

These methods have different diagnostic accuracy. On the other hand diagnosis in the signal space is increasingly used and provides more accurate data. At the same time the disadvantage of the method is loss of network performance due to the expense of the resource on the transfer test-signals. Let us consider in more in detail the method of diagnosis.

TCS is a multidimensional controlled dynamic system, its functional state within the linear approximation is represented in the form of a stochastic differential control [7, 8]:

$$x(k+1)=F(k+1,k)x(k)+G(k)\xi(k), \tag{1}$$

where $x(k)$ – n-dimensional state vector of the system; $F(k+1,k)$ – transition matrix [$n\times n$]; $\xi(k)$ – l-dimensional vector of random - sample of white Gaussian noise (WGN), generating the random character of the state, the power spectral density of the noise $N_\xi(k)$; $G(k)$ – scaling matrix of random components [$n\times l$].

The equation for observation (measurement) of test signals:

$$y(k)=H(k)x(k)+\nu(k), \tag{2}$$

where $y(k)$ – s-dimensional vector of measurements; $H(k)$ – matrix of observations [$s\times n$]; $\nu(k)$ – dimensional random sequence is not correlated $\xi(k)$ and is the observation noise, and represents a sample of WGN with the spectral power density $N_\nu(k)$.

The essence of the process $x(k)$ can be a sequence of currents or voltages at the output of individual nodes or network elements, the data of the respective agents, and other physical parameters of the sequence of processes in telecommunication networks: a sequence of data packets delay, jitter, time intervals between consecutive packets, etc.

As we studied the process $x(k)$ in the form of (1) the presence of observable components (2) allows assessing $\hat{x}(k)$ on the each of k-steps. It is known [10, 11] that for the Gaussian situation when choosing a criterion of quality assessment in the form of a minimum mean squared error estimation, the latter can be found on the procedure for the Kalman - Bucy:

$$\hat{x}(k) = F(k-1,k)\hat{x}(k-1) + K(k-1)[H(k)F(k-1,k)\hat{x}(k-1) - y(k)], \quad (3)$$

where $K(k-1) = P(k-1)H^T(k)N_v^{-1}(k-1)$, $P(k-1) = [I - K(k-1)H(k)]P(k-1,k)$,

$$P(k-1,k) = F^T(k-1,k)P(k-1)F(k-1,k) + N_\xi(k-1), \quad (4)$$

where the last equation defines a posterior error variance estimate (of residual detunes).

Detune $\delta(k)$ is determined by the difference in the square brackets of equation evaluation (3). From the theory of innovation process it is known [7], that in case of optimal estimation (3) the sequence of residual detunes $\delta(k)$ is a sample of a Gaussian white noise with zero mean $E[\delta(k)] = 0$.

Knowledge of the statistical parameters of the test signals allows to provide an optimal filter (3). Any change an the state (1) or the results of measurement (2) leads to the deviation of residual detunes $\delta(k)$ from the characteristics WGN with zero mean an increase in the level of the posterior dispersion error of estimate (6).

Thus, the analysis of residual detunes parameters provides information on the function of the observed deviation from the optimal system or its calculated mode. We pose the problem of detecting the residual detunes parameters. In the simplest case, we consider two hypotheses:

$H_0 : \delta(k) \le \delta_n$ – changes in the status of the system are absent;

$H_1 : \delta(k) > \delta_n$ – changes in system conditions change are present,

here δ_n – threshold of residual detunes.

The question of what the cause of change and their localization are represents a separate task, in which it is necessary to take into account the specifics of the situation and the structure of the network. We know methods of reducing the sequence of residuals to a form suitable for practical use [12]. For this, let us consider the matrix of residual detunes $\theta(k) = \{\delta_{n\times m}\}$ size $n \times m$, where m – corresponding readings of times, that is, we will consider the matrix whose columns are the n-residuals corresponding n - states of the diagnostic objects. The matrix $\theta(k)$ of arbitrary type is difficult to work with. It is much easier to work with the spectrum of the matrix (SOM), where λ_i – the value of its own. However, you can further simplify the SOM. It makes sense to use its spectral norm, defined by λ_i – through the eigenvalues of the matrix $\{\theta^T(k)\theta(k)\}$:

$$\|\theta(k)\|_2 = \max\{(\lambda_i[\theta^T(k)\theta(k)]\}^{1/2}\},$$

where $\{(\lambda_i[\theta^T(k)\theta(k)]\}^{1/2}\}$ is called the singular value matrix of residual detunes $\theta(k)$ [9].

An analytical expression for the upper confidence limit of the spectral norm of the matrix $\theta(k)$, assuming Gaussian probability distribution residuals and the normalization $\delta(k)$ of its own values.

We use the Frobenius norm of a matrix $\theta = [\theta_{ij}] \in R^{n\times m}$ by defining it through the trace *tr*:

$$\|\theta\|_F = \sqrt{tr\left(\theta^T\theta\right)} = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m}\theta_{ij}^2}\ .$$

Frobenius norm and the spectral norm correlated as [4]:

$$\|\theta x\|_2 \le \|\theta\|_F \|x\|_2 , \tag{5}$$

where $x \in R^m$ is a randomly distributed non-zero vector.

Obviously, inequality (5) will continue at the maximum left side:

$$\max_{x \ne 0} \frac{\|\theta x\|_2}{\|x\|_2} \le \|\theta\|_F\ .$$

It can be shown that the matrix norm associated with a corresponding vector norm:

$$\|\theta\| = \max_{x \ne 0} \frac{\|\theta x\|}{\|x\|}\ .$$

If the vector norm as to choose the Euclidean norm $\|x\|_2$, the corresponding matrix norm is the maximum singular value of the matrix $\theta(k)$ [4, 5]:

$$\|\theta\| = \sigma_{\max}[\theta] \le \|\theta\|_F\ . \tag{6}$$

In our Gaussian when $\theta_{ij} \in N(0,1)$, amount $\sum_{i=1}^{n}\sum_{j=1}^{m}\theta_{ij}^2$ will have χ^2 a distribution with $k = nm - 1$ degrees of freedom. Thus from (6) we have:

$$\sigma_{\max}[\theta] \le \|\theta\|_F = \sqrt{\chi^2}\ . \tag{7}$$

To determine the allowable values the upper confidence limit of the spectral norm of the matrix of normalized of residual detunes θ we assume a confidence level of $\beta = 1 - \alpha$, where $\beta = P\left\{\chi^2 \le \chi^2_{\beta(nm-1)}\right\}$. Next, substituting $\chi^2_{\beta(nm-1)}$ from (7) we finally obtain:

$$\sigma_{\max}[\theta] \le \sqrt{\chi^2_{\beta(nm-1)}}\ . \tag{8}$$

In case of non-fulfillment of the condition (8) the process of the network performance is considered as disturbed. It remains to clarify the question of choosing a window size of m to form the matrix of residual detunes. Strictly speaking, the sufficiency of the statistics is obtained in the case $m \to \infty$. However, given the presence of commonly occurring unsteadiness this interval should not exceed the interval quasistationarity [6].

In the presence of disorder in the system when $\sigma_{\max}[\theta] > \sqrt{\chi^2_{\beta(nm-1)}}$ at the large dimension $x(k)$ there is uncertainty associated with the search for the causes of such a disorder. As one of the methods for resolving this uncertainty we can use the respective individual filters operating in accordance with the algorithm (3) for each of components diagnosed by x_i.

Conclusion

1. The proposed method of diagnosing the quality of telecommunications systems solved in the space of signals on the principle of "learning with a teacher" has a higher reliability than the method solved in the parameter space.

2. The residual detune, obtained due to result of best estimation system as a result of a "supervised learning", has the most complete information about the state of the system deviation from the desired characteristics. Therefore, the method based on the use of the statistical characteristics of the sequence of residual detunes (the matrix of residual detunes) to diagnose the quality of functioning of TCS is the most informative.

3. The upper confidence limit of the spectral norm of the matrix normalized for residual detunes can be used as a threshold function for detecting disorders (disorder) in the state of the system.

4. In order to localize the causes of disorder it may be recommend to use of individual assessment of filters for each object of diagnosis.

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