IDENTIFICATION OF THE STATES OF THE SYNCHRONIZATION SYSTEM BASED ON ITS ENTROPY ANALYSIS

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Purpose: **To provide reasonable identification of the states of the process of functioning of the synchronization system in communication networks for making rational and operational decisions on its management and technical operation. It is proposed to achieve this goal by forming an entropy model of the dynamics of the synchronization system based on the analysis of the values of its diagnostic parameters. To identify the state of the process of functioning of the synchronization system, it is proposed to use differential entropy as a system-wide parameter for evaluating systems. The calculation of the differential entropy of the synchronization system is based on the values of the differential entropy of its elements, which are estimated based on the assessment of diagnostic parameters. Further identification of states is carried out by using pattern recognition algorithms. *Methods:* research methods are used in the work, which are based on the principles of the theory of networks and systems, system and mathematical analysis, entropy and mathematical modeling. *Results:* as a result of the research, an entropy model of the dynamics of the synchronization system was obtained, an approach was proposed for assessing the state of the synchronization system by analyzing its differential entropy as a system-wide parameter. *The theoretical significance* of the work lies in the expansion of the methodological base for the construction of control systems for the synchronization of communication networks. *The practical significance* of the work lies in the use of the obtained results for the design and modernization of synchronization control systems in the field of forming reasonable management decisions.**

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Introduction

The efficiency and quality of the process of functioning of modern and promising telecommunication systems significantly depends on the synchronization system that is part of it. The synchronization system is necessary for the formation, transmission and distribution of synchronization signals to the digital equipment of the telecommunication system in order to ensure their coordinated interaction, to maintain the required quality of communication services at the proper level. Thanks to the synchronization system in the telecommunication system, the clock frequency of the digital signals of the required level is maintained, as well as the stability of the master generators. The functioning of the synchronization system is carried out using the principle of forced synchronization. The need for synchronization signals arises both in networks with channels switching and in networks with packages switching. The occurrence of failures in the synchronization system helps to reduce the performance of related subsystems of the telecommunications system [1-3].

The synchronization system is a complex heterogeneous structure that closely interacts with adjacent subsystems of the telecommunications system. Elements of the synchronization system interact with each other through standard interfaces, which are defined by national and international recommendations. The high-quality functioning of the synchronization system is possible only with the organization of an effective management system, which, as a rule, has a multi-level hierarchical structure in accordance with the regions of synchronization.

Direct maintenance of the synchronization system is carried out through the technical operation system, which performs the functions of monitoring, conducting the necessary measurements, repairing and backing up if necessary. Delivery of synchronization signals to end users is carried out through a synchronization network, which includes various types of generator equipment, means of delivery, distribution, retiming, recovery, and conversion of synchronization signals [4, 5].

Thus, the generalized block diagram of the synchronization system has the form shown in Figure 1.

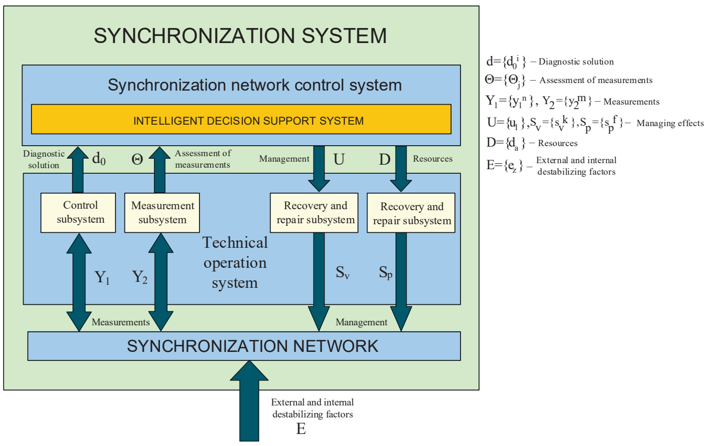

Fig. 1. Generalized structural diagram of the synchronization system

It should be noted that the synchronization system in general form is superimposed on the adjacent subsystems of the telecommunication system, so it includes elements of guide systems and transmission systems.

1. The use of differential entropy to assess the technical condition of the synchronization system and its elements

Entropy is a general system parameter, which is used to assess the state of various structures, regardless of the subject area of application. To assess the state of objects that differ in significant complexity and stochastic nature, which are characterized by many parameters and relationships, the use of differential entropy is possible [6].

In general, differential entropy is determined according to the formula (1) [7, 8]:

$$H = -\int_{-\infty}^{+\infty} f(x)\ln f(x)\,dx \qquad (1)$$

where $f(x)$ is the density of the distribution of the signal of the continuous source.

The synchronization system is a complex dynamic stochastic system, therefore, to assess its condition, it is possible to use differential entropy [7].

The assessment of differential entropy of the synchronization system can be made through an assessment of the differential entropy of its elements. To do this, it is necessary to represent each element of the synchronization system in the form of Y (2).

$$Y = (Y_1, Y_2, ..., Y_m) \qquad (2)$$

The elements of the vector (2) $Y_1, Y_2, ..., Y_m$ are the values of the diagnostic parameters. Each element of the synchronization system is characterized by its set of diagnostic parameters, so vectors (2) for various elements of the synchronization system will be different [7, 9].

As general diagnostic parameters of the synchronization system and its elements, according to regulatory documents, you can distinguish [1, 3]:

– re ative deviation of the frequency of synchrosignal from its nominal value;

– the level of the phase of the synchrosignal phase at the entrance and output of equipment, expressed through MTIE and TDEV;

– accuracy of memorization and maintenance of frequency in the frequency retention mode;

– noise resistance to phase noise;

– he values of the gear characteristics for phase wandering.

For elements operating in networks with packages switching, the following diagnostic parameters are used [1, 3]:

– accuracy of synchronization of data on the current value of a second reference number;

– accuracy of the restoration of the interval of 1 Hz and the reference frequency;

– accuracy of synchronization of the initial phase of second references.

The listed diagnostic parameters are usually measured in predetermined control points of the synchronization network. These diagnostic parameters can be supplemented by common -set parameters obtained using the *SNMP* protocol or proprietary protocols of equipment manufacturers.

To estimate the differential entropy of an element of the synchronization system, we introduce the following assumptions:

– he vector $Y = (Y_1, Y_2, ..., Y_m)$ has a multivariate normal distribution;

– for a vector $Y=(Y_1,Y_2,...,Y_m)$ it is possible to calculate the covariance matrix Σ (3).

$$\Sigma=\begin{pmatrix}\sigma_{Y_1}^2 & \mathrm{cov}(Y_1,Y_2) & ... & \mathrm{cov}(Y_1,Y_m)\\ \mathrm{cov}(Y_2,Y_1) & \sigma_{Y_2}^2 & ... & \mathrm{cov}(Y_2,Y_m)\\ ... & ... & ... & ...\\ \mathrm{cov}(Y_m,Y_1) & \mathrm{cov}(Y_m,Y_2) & ... & \sigma_{Y_m}^2\end{pmatrix} \quad (3)$$

It is noted in [7] that the analytical determination of the entropy $H(Y)$ at the moment is possible only for a joint normal distribution. When using third-party distributions, there is no possibility of finding a value that is similar to the determinant of the correlation matrix for the joint normal distribution [7]. Nevertheless, the use of a multivariate normal distribution looks legitimate due to the significant complexity of the synchronization system and the diversity of its elements. Estimation of the covariance matrix of the vector *Y* is possible by analyzing the statistics of the technical operation of the synchronization system and its elements.

The differential entropy of an element of the synchronization system can be estimated using formula (4) [7]:

$$H(Y)=\frac{1}{2}\ln\left[(2\pi e)^m|\Sigma|\right]=\sum_{i=1}^{m}H(Y_i)+\frac{1}{2}\ln|R|=H(Y)_\Sigma+H(Y)_R \quad (4)$$

where $|\Sigma|$ is the value of the determinant of the covariance matrix Σ of the vector *Y*; $|R|$ is the value of the determinant of the correlation matrix *R* of the vector *Y*.

Expression (4) allows us to conclude that the entropy of an individual element of the synchronization system is the sum of two quantities. The value $H(Y)_\Sigma$ determines the limiting differential entropy, which corresponds to the complete independence of the diagnostic parameters of the element of the synchronization system (entropy of chaos). The value $H(Y)_R$ shows the degree of interrelationships between diagnostic parameters (entropy of self-organization). Expression (4) also shows that the differential entropy of an element of the synchronization system can change due to a change in the dispersion of the values of diagnostic parameters, as well as due to a change in the correlation of diagnostic parameters [7, 10].

Tracking in continuous mode the change in the differential entropy of an element of the synchronization system, you can track its state, for this it is necessary to evaluate the change in the entropy of chaos and the entropy of self-organization. If there was an increase in the entropy of chaos, then there was an increase in the scatter of the data of diagnostic parameters; with a decrease in the entropy of chaos, the scatter of the data decreased. Similarly, if the entropy of self-organization increased, then processes occurred in the element of the synchronization system that led to a decrease in the relationship of diagnostic parameters. With a decrease in the entropy of self-organization, the relationship between diagnostic parameters increased [7, 10]. By estimating the entropy of chaos and the entropy of self-organization, it is possible to track the contribution of each diagnostic parameter to the change in the state of an element of the synchronization system.

Applying the approach for estimating the differential entropy of an element of the synchronization system in a similar way, it is possible to estimate the differential entropy of the entire synchronization system or its fragments. According to the dynamics of the change in differential entropy, it is possible to find failed elements, or elements whose functioning goes beyond the normative values.

2. Identification of the state of the synchronization system based on the estimation of its differential entropy

Identification of the states of the synchronization system is necessary in order to make informed decisions on its management. Each state of the synchronization system can be associated with a certain set of plans and strategies in the development of management decisions to maintain its functioning process.

There is the possibility of many states of the synchronization system to divide into subsets, each subset of the conditions put one or more typical managerial decisions into line. Thus, the task of managing the synchronization system is reduced to the classification and identification of its conditions. Each state is characterized by a certain set of diagnostic parameters, which means a certain set of values of the entropy of the elements of the synchronization system and the value of the entropy of the entire system.

To identify conditions, it is possible to use images recognition algorithms. The recognition of images in this case means attributing the state to one of the known classes [11, 12]. In general, three modes of recognition of images can be distinguished: recognition without training, recognition with partial learning and recognition with learning.

To identify the states of the synchronization system, it is possible to use learning recognition algorithms, since the synchronization system is a complex technical system with many conditions and is regularly undergoing modernization, reconfiguration of elements and means of synchrosignal delivery.

In recognition with training, many states of the synchronization system can be divided into classes $\omega_1, \omega_2, \ldots, \omega_k$, each of which is characterized by certain values of entropy. The values of the elements of the synchronization system are calculated by expression (4) based on the values of diagnostic parameters at a given moment in time. Accordingly, classes can be represented by training samples (5):

$$\begin{aligned}&\{X_{1_1},X_{2_1},...,X_{n_1}\}\subset\omega_1,\\&\{X_{1_2},X_{2_2},...,X_{n_2}\}\subset\omega_2,\\&......................................\\&\{X_{1_k},X_{2_1},...,X_{n_k}\}\subset\omega_k,\end{aligned} \quad (5)$$

where X_{n_k} is the value of the entropy of the element n of the synchronization system when related to the *k*-th state. In the general case, ω_k is a vector consisting of n elements [13].

The new or current state of the synchronization system must be attributed to one of the existing classes (5). In the general case, this condition may coincide with any of the conditions included in the classes $\omega_1, \omega_2, \ldots, \omega_k$ or to be in the range of classes of states.

Having thus identified the condition, it is possible to further correlate it from the already existing managerial decision.

Initially, it is necessary to determine the main possible states of the synchronization system. Among the main states, it is necessary to highlight the condition in which the synchronization system function with the characteristics that correspond to the regulatory values, and the conditions corresponding to the failures of the elements, generator equipment and the delivery means of synchronization signals are also possible, and the release of intermediate states is also possible.

The correlation of the current state with reference ones is possible using the correlation algorithm and the distance in distance. The correlation algorithm consists in determining the correlation of the current state of the synchronization system with each of the reference states. When using this algorithm, the state X refers to the class of states for which the correlation coefficient is the largest [11-14].

The correlation coefficient (CC) between the states X_i, X_j determines the measure of their angular proximity and is expressed through their normalized scalar product (6):

$$\rho(X_i, X_j) = \frac{(X_i, X_j)}{|X_i| \cdot |X_j|},\ i,j=1,2,\ldots,n \quad (6)$$

expression can be represented as (7):

$$\rho(X_i, X_j) = \frac{\sum_{s=1}^{p} x_{is} \cdot x_{js}}{\sum_{s=1}^{p} x_{is}^2 \cdot \sum_{s=1}^{p} x_{js}^2}\quad i,j=1,2,\ldots,n \quad (7)$$

The classes of states of the synchronization system $\omega_1, \omega_2, \ldots, \omega_k$ will be represented by our training samples.

We represent the training samples of states $\omega_1, \omega_2, \ldots, \omega_k$ as average entropy values for each state (8).

$$\mu_1 = \frac{1}{n_1}\sum_{i=1}^{n_1} X_{i_1}$$
$$\mu_2 = \frac{1}{n_2}\sum_{i=1}^{n_2} X_{i_2} \quad (8)$$
....
$$\mu_k = \frac{1}{n_k}\sum_{i=1}^{n_k} X_{i_k}$$

where k is the total number of reference states, μ_k is the standard (average value) of the entropy of the k-th class of states of the synchronization system, n is the number of elements of the synchronization system, according to which the entropy is calculated [11-14].

The correlation of states, which are a vector, is determined by the cosine of the angle between them. The cosine of the angle between the state vectors can be calculated from the scalar product of the vectors (9):

$$(X, \mu_1) = |X||\mu_1|\cos\alpha_1$$
$$(X, \mu_2) = |X||\mu_2|\cos\alpha_2 \quad (9)$$
....
$$(X, \mu_k) = |X||\mu_k|\cos\alpha_k$$

where X is the current state vector. α_k is the angle between the current state vector and the k -th reference state vector.

From (9) we obtain (10):

$$\cos\alpha_1 = \frac{(X, \mu_1)}{|X||\mu_1|}$$
$$\cos\alpha_2 = \frac{(X, \mu_2)}{|X||\mu_2|} \quad (10)$$
....
$$\cos\alpha_k = \frac{(X, \mu_k)}{|X||\mu_k|}$$

The scalar product of vectors and their moduli can be calculated in terms of their coordinates in n-dimensional space:

$$X = (X_1, X_2, \ldots, X_n)$$
$$\mu_1 = (X_{1_1}, X_{1_2}, \ldots, X_{1_n})$$
$$\mu_2 = (X_{2_1}, X_{2_2}, \ldots, X_{2_n}) \quad (11)$$
....
$$\mu_k = (X_{k_1}, X_{k_2}, \ldots, X_{k_n})$$

$$(X, \mu_1) = X_1 X_{1_1} + X_2 X_{1_2} + \ldots + X_n X_{1_n}$$
$$(X, \mu_2) = X_1 X_{2_1} + X_2 X_{2_2} + \ldots + X_n X_{2_n} \quad (12)$$
....
$$(X, \mu_k) = X_1 X_{k_1} + X_2 X_{k_2} + \ldots + X_n X_{k_n}$$

$$|X| = \sqrt{X_1^2 + X_2^2 + \ldots + X_n^2}$$
$$|\mu_1| = \sqrt{X_{1_1}^2 + X_{1_2}^2 + \ldots + X_{1_n}^2}$$
$$|\mu_2| = \sqrt{X_{2_1}^2 + X_{2_2}^2 + \ldots + X_{2_n}^2} \quad (13)$$
....
$$|\mu_k| = \sqrt{X_{k_1}^2 + X_{k_2}^2 + \ldots + X_{k_n}^2}$$

Having calculated the cosines of the angles between the vectors, it is necessary to find the largest one (14).

$$\max_k \cos\alpha_{ik} = \cos\alpha_{ik_0} \quad (14)$$

The expression (14) suggests that the angle between the vector of the current state and the found vector found, and, accordingly, the current state of the synchronization system can be attributed to the found class of states [11-14].

If the condition of the equality of cosine values is fulfilled, and these cosine are the greatest, then the current state of the synchronization system can be attributed to any of these class classes.

Decisions obtained using the correlation algorithm are based on the angular proximity of state vectors. The algorithm is applicable if the angles between vectors within the same class are quite small in comparison with the corners between classes of classes. Decisions obtained by the correlation algorithm can be supplemented by decisions obtained when using the algorithm in distance.

When using the algorithm in distance, the distances are calculated from the current state to all possible in the n-dimensional space. Subsequently, it is necessary to compare the found distances and select the smallest (15).

$$\min_n r_{in} = r_{in_0} \qquad (15)$$

The value of i, for which the distance is minimal, determines the class of states of the synchronization system. It should be noted that if the found distances are sufficiently large and greater than the minimum class diameter, then the current state should be assigned to a new class [11-14].

The block diagram of the methodology for identifying the states of the synchronization system is shown in Figure 2.

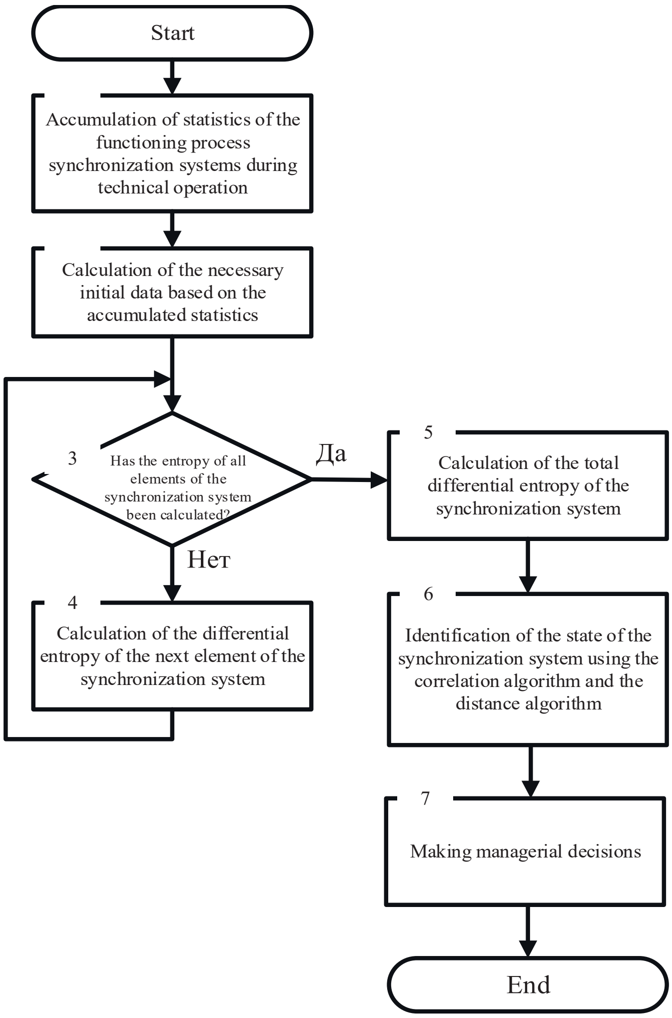

Fig. 2. Block diagram of the technique for identifying the states of the synchronization system

The integrated use of the above algorithms makes it possible to reliably identify the state of the synchronization system, which in the future will make it possible to reasonably make management decisions.

Conclusion

The synchronization system is a structure, the functioning of which determines the performance of the entire telecommunications system and the quality of communication services.

Refusals in the synchronization system apply to refusals in adjacent subsystems and the entire telecommunications system as a whole. Thus, the task of constructing an effective synchronization management system that can reasonably and quickly develop managerial decisions is relevant. The key issue in the development of managerial decisions is the identification of the state of the synchronization system. To resolve this issue, the use of differential entropy as a common -system parameter, which allows all possible diagnostic parameters to reduce to the same value and compare. The further issue of identification is reduced to the classification of states, the solution of which is made by using images recognition algorithms. The results can be used in existing and designed synchronization management systems by forming the relevant software systems.

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ИДЕНТИФИКАЦИЯ СОСТОЯНИЙ СИСТЕМЫ СИНХРОНИЗАЦИИ НА ОСНОВЕ ЕЁ ЭНТРОПИЙНОГО АНАЛИЗА

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Аннотация
Цель: Обеспечить обоснованную идентификацию состояний процесса функционирования системы синхронизации в сетях связи для принятия рациональных и оперативных решений по её управлению и технической эксплуатации. Достижение данной цели предлагается осуществить путем формирования энтропийной модели динамики системы синхронизации на основе анализа значений её диагностических параметров. Для идентификации состояния процесса функционирования системы синхронизации предлагается использовать дифференциальную энтропию как общесистемный параметр оценки систем. Вычисление дифференциальной энтропии системы синхронизации производится на основе значений дифференциальной энтропии её элементов, которые оцениваются на основе оценки диагностических параметров. Дальнейшая идентификация состояний осуществляется путем использования алгоритмов распознавания образов. *Методы:* в работе использованы методы исследования, которые основаны на положениях теории сетей и систем, системного и математического анализа, энтропийного и математического моделирования. *Результаты:* в результате проведенных исследований получена энтропийная модель динамики системы синхронизации, предложен подход по оценке состояния системы синхронизации путём анализа её дифференциальной энтропии как общесистемного параметра. *Теоретическая значимость* работы состоит в расширении методической базы по построению систем управления синхронизацией сетей связи. *Практическая значимость* работы заключается в использовании полученных результатов для проектирования и модернизации систем управления синхронизацией в области формирования обоснованных управленческих решений.

Ключевые слова: *идентификация, телекоммуникационная система, система синхронизации, дифференциальная энтропия, распознавание образов.*

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