# Method of Improving the Stability of Network Synchronization in Multiservice Macro Networks

Yurii Khlaponin [1] [0000-0002-9287-0817], Elissawi Kamal Khalifa [2] [0000-0002-5287-0911], Dmytro Khlaponin [2] [0000-0002-7797-4319], Alexander Selyukov [1] [0000-0001-7979-3434], Andrii Tolbatov [3] [0000-0002-9785-9975] and Volodymyr Tolbatov [4] [0000-0002-6564-9658], Roman Odarchenko [5,6,7] [0000-0002-7130-1375]

[1] Kyiv National University of Construction and Architecture, Kyiv, Ukraine
[2] State University of Telecommunications, Kyiv, Ukraine
[3] Sumy National Agrarian University, Sumy, Ukraine
[4] Sumy State University, Sumy, Ukraine
[5] National Aviation University, Kyiv, Ukraine
[6] State Scientific and Research Institute of Cybersecurity Technologies and Information Protection, Kyiv, Ukraine
[7] Yessenov University, Aktau, Kazakhstan

y.khlaponin@gmail.com, kamalelissawi@yahoo.com, kmld85@gmail.com, selukov@3g.ua, tolbatov@ukr.net, tolbatov302@gmail.com, odarchenko.r.s@ukr.net

**Abstract.** The technique of determining the stability of the network synchronization functioning for each of the fragments of the synchronization network under the given initial conditions is developed: failure rate, recovery intensity and initial conditions in which the system was located and taking into account the following parameters: algorithm of operation of the synchronization node; a way to set priorities for input interfaces (ports) of synchronization; establishment of quality levels (quality level) of synchronization signals; is the network fragment topology. The generalized functionality of synchronization network stability is obtained, which determines the dependence of the reliability of the synchronization network on the functional dependencies between the intensities of failure and recovery flows, network topology, scheduling efficiency, algorithms for the operation of network elements.

**Keywords:** network, synchronization, topology, constancy of synchronization, quality of network operation, algorithm.

## 1 Introduction

Active evolutionary development of technologies leads to the creation of multiservice macros, which will be aimed at solving fundamentally new problems. It is not uncommon when the number of nodes that require synchronization reaches more than 1000 in one operator, and the topological structure of the network thus becomes lat-

 CybHyg-2019: International Workshop on Cyber Hygiene, Kyiv, Ukraine, November 30, 2019.

tice-like. The reason for this complication of the topological structure is the expansion of the functionality of the equipment. Therefore, for the effective functioning of multiservice macrosets, it becomes necessary to adequately complicate the topological structure of network synchronization.

One of the main tasks is to build network synchronization, the reliability of which should not be inferior to the reliability of the data network. Since there are mechanisms in place to protect traffic from possible accidents, the synchronization network should be designed to take account of possible changes in the data transmission routes. The fulfillment of such a requirement in the synchronization networks is connected with the need to build an optimal “logical” synchronization tree. The quality of network synchronization depends on the quality of network synchronization functioning in the multiservice macros

## 2 Analysis of recent research and publications.

The formation of new generation transport networks based on packet technology poses a number of serious problems. The basis of these problems is the contradiction between the need to keep a clear queue in the transmission of streaming messages and the basic principle of packet technology, which is the non-compliance with the queue when receiving packets. Thus, it becomes urgent to solve the problem of providing data transmission in packet-switched networks with the same quality as that provided by the digital synchronous hierarchy. This actually means that you need to emulate a synchronous dial-up network with a packet-switched network. In addition, such a transport network should be transparent to any type of terminal equipment, including SDH, leading to the need to provide synchronization signals with the specified quality of the SDH edge equipment. This goal can be achieved by creating a common network synchronization that will synchronize both the SDH equipment and the packet network equipment. When creating this network, it is necessary to take into account the fact that the topological structure of packet networks is much more complex than traditional network switched networks. For example, digital synchronous hierarchy networks are typically multi-ring structures, and packet networks have a lattice or star topology. Thus, to ensure the specified quality of the functioning of the next generation transport network, it is necessary to ensure reliable delivery of synchronization signals to the network equipment, which is achieved by optimal planning of network synchronization [1-6].

In the transition to multi-service macros, one of the main tasks is the task of building network synchronization, which should not be inferior to the data transmission network for reliability and consistency.

Solving the scientific problem of improving the sustainability of network synchronization requires the study of the dependencies of the reliability of the network functioning on the selected network topology, the algorithm used for the network element, the intensity of failures and recoveries.

To solve this problem, consider the typical topological fragments of networks on which network synchronization can operate. We analyze these topological structures using a mathematical apparatus of the theory of Markov random processes with discrete states and continuous time [8-14].

The main types of topological structures used in synchronization networks are tree and annular, which will be taken as typical for research. As a promising topology that can be used, a fragment with a triangular topological structure is proposed.

The main tasks to be solved in the article are:

- determination of a set of parameters that affect the continuity of network synchronization;
- development of recommendations for the optimal construction of network synchronization based on combinations of topological structures, which consist of the studied fragments;
- research of dependence of constancy of functioning of fragment of network synchronization on intensity of failures, intensity of restorations and selected topology;
- the choice of the optimum topology, which provides the maximum stability of network synchronization at the given intensities of flows of failures and restorations.
- exploring the possibility of using typical fragments of a synchronization network to build a dynamically adaptable synchronization tree.

As a criterion for the application of the type of topology, we consider the efficiency of this fragment. We formulate the determination of the performance of the fragment. A fragment of a synchronization network consisting of network nodes and communication lines is considered operable if it is able to function with a predetermined quality of the synchronization signal for a certain period of time.

Therefore, changing the quality of the clock signal to the downside even after a long period of time will be considered as a disability after failure.

### 2.1 Introducing of synchronization network on a base of a graph theory

For convenience of presenting the studied graphs and formal procedures with them, at the levels of teaching (calculation examples) and constructing models on the PC, we numbered the elements of the graph.

Concepts, definitions, notations and mathematical symbols are used in accordance with the notation in graph theory [1, 3, 7, 13]. The numbering procedure is follow:

- - the vertices of the graph are numbered from 1 to $m_v$ arbitrary,
- -where $m_v$ is the power of the set of vertices of the graph;
- - the edges of the graph are numbered using the following algorithm: if the given graph and the vertices of the graph are numbered, then the variable ν is assigned a value $m_v$; if the vertex $v_i$ is adjacent $v_j$ to the edge $l_{i,j}$, then the $i < j$ operation is performed $v = v + 1$ and this edge is assigned a number whose value is equal ν.

## 2.2 Analysis of a network fragment with a triangular topological structure

The transport network of a multi-service macro network can be considered as a set of typical topological fragments. These are tree, annular and triangular topological structures. To analyze the principles of building a synchronization network, consider one of the typical topological fragments of a transport network with a triangular topological structure.

A triangular topological structure is a minimal, fully connected structure that assumes a closed loop. Also, this structure provides three independent sources of synchronization. Let us evaluate the possibility of maintaining a given quality of functioning of network synchronization, which can be represented by a triangular topology (Fig. 1). When evaluating the quality of network synchronization, the effect on the selected topological fragment of failure and recovery streams having Poisson distribution is taken into account.

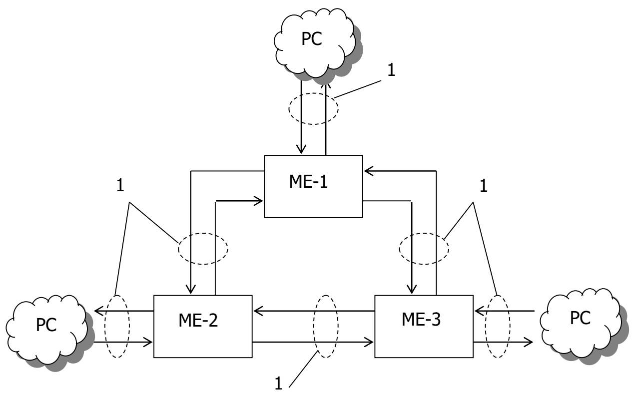


**Fig. 1.** Scheme of network synchronization fragment

ME-1, ME-2, ME-3 - the network element of the clock network; 1 - synchronization route; PC is the region of synchronization.

For a formal description of the fragment of the synchronization network, we use graph theory (Fig. 2).

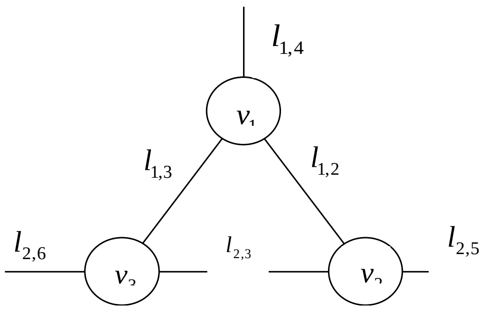


**Fig. 2.** Representation of a triangular topological structures in the form of a graph

$v_1$, $v_2$, $v_3$ - vertices of the graph representing the nodes of the clock network; $l_{1,2}$, $l_{2,3}$, $l_{1,3}$ - edges of the synchronization graph representing the track between the nodes of the studied fragment; $l_{1,4}$, $l_{2,5}$, $l_{3,6}$ - edges of the synchronization graph, representing the route between the nodes of the study fragment and external to the given fragment nodes.

## 3 Generalizing algorithm for analyzing the performance of an arbitrary topology synchronization network fragment

The purpose of developing a generalization algorithm is the need of evaluating of the performance of synchronization network fragment by generalizing of the algorithms to specific configurations [13-18].

Let the network fragment have a finite number of discrete states, and failures and recoveries in that fragment occur at random times. Thus, the operation of an arbitrary fragment of the clock network may be represented by a random process with a finite number of discrete states, and continuous time.

Assume that all flows that translate the studied fragment from one state to another - Poisson and independent, resulting in a random process of transitions from one state to another under the action of flows of failures and recoveries, is a Markov process with discrete states and infinite time.

Given these assumptions, it is possible to present a generalized algorithm in the form of a sequence of steps.

Step 1. Let`s present the explored fragment in the form of a graph, in which the vertices of the graph correspond to the network elements and the edges of the graph are the connections between the network elements. Let's carry out the procedure of numbering the graph.

Step 2. Let`s define a complete group of incompatible events, that determine all possible states of an arbitrary fragment of the network.

Step 3. Determine the functions of the intensities of the failure flows and the restoration flows of the species $\lambda_{ij}(t)$ and $\mu_{ji}(t)$ which translate the studied fragment from one possible state to another (for example, from the state $S_i$ in $S_j$).

Step 4. Using a group of incompatible events, we construct a marked graph of the states of the network fragment.

Step 5. On the basis of the marked graph, we construct a system of differential equations using the following mnemonic rule: the derivative of the probability of any state is equal to the sum of all the streams of probabilities that transfer the system to this state, minus the sum of all the streams of probabilities that derive the system from this state, and exactly:

$$\frac{dp_i(t)}{dt} = \sum_{j=1}^{n} p_j(t) \cdot \mu_{ji}(t) - p_i \cdot \sum_{j=1}^{n} \lambda_{ij}(t) ; \quad (i = 1, 2, \dots, n) \qquad (1)$$

Step 6. Determination of the probability of finding the network in one of the possible states by solving the system of differential equations (1).

Step 7. Determination of the condition that leads to the loss of performance of the fragment of the clock network, taking into account the following parameters and criteria defining the concept of "performance":

- algorithm of operation of the synchronization node;
- a way to set priorities for input interfaces (ports) of synchronization;
- establishment of quality levels (quality level) of synchronization signals;
- is the network fragment topology.

For example, for a triangular fragment, this condition is expressed by formula (2).

Step 8. Divide all incompatible events into two groups. The first group of events includes those events that do not significantly affect the quality of the network. The second group of events includes those events, each of which leads to a loss of network performance.

Step 9. Determining the probability of finding a fragment of the clock network in a working or inoperable state, taking into account the distribution of states by groups.

$$P(M_{Tp}) = \sum_k p_k + \sum_m p_m\,; \qquad (2)$$

where $k$ is the index for the states in the group corresponding to the performance of the fragment;

$m$ is the index for the states in the group corresponding to the disability of the fragment;

$n = k+m$ is the number of independent states of the marked graph of the system.

## 4 Comparative analysis of the functioning of fragments of the synchronization network

Let us perform a comparative analysis of the investigated fragments of the synchronization network (triangular, tree, annular), based on the above relations for the probability of finding each fragments in working condition.

In the first step, we determine the reliability of each fragment, provided that the failure rates and the recovery rates of the data of the fragments of the synchronization network are equal, that is:

$$\lambda_{Tr} = \lambda_{Dr} = \lambda_K$$
$$\mu_{Tr} = \mu_{Dr} = \mu_K$$

We introduce the definition of the structural reliability of the clock network. The structural reliability of the clock synchronization network means the objective property of the network to provide connectivity between the nodes of the network with the quality of the synchronization signal is not worse than specified. With respect to the studied fragments of the clock synchronization network, structural reliability is defined as the probability of finding the fragment of the clock network in a working state by formulas (3.31), (3.43), (3.55).

The structural reliability of the synchronization network in general is a function dependent on the intensity of the failure stream, the intensity of the recovery stream, the topology, and the algorithm of operation of the node of the clock synchronization network. Thus, structural reliability can be represented in the following form:

$$P = f\left[\lambda_i(t), \mu_i(t), R_j(t), F_k\right],$$

where $\lambda_i(t)$ – a bounce rate function that affects the *i*-th element of a network fragment;

$\mu_i(t)$ – the intensity of the failure flow that affects the *i*-th element of the network fragment;

$R_j(t)$ – the topology of the fragment under study (j = 1÷3, where j = 1 corresponds to a triangular fragment, j = 2 to a tree fragment, j = 3 to a circular fragment);

$F_k$ - type of used algorithm, where $k$ = 1÷3, where $k$ = 1 corresponds to the algorithm of operation of the synchronization nodes based on the priority tables, $k$ = 2 corresponds to the algorithm of operation of the synchronization nodes based on the status messages, $k$ = 3 corresponds to the algorithm of the operation of clock synchronization nodes with synchronization programmable delay.

Consider the dependence of the change in the structural reliability of the fragments of the synchronization network on the failure rate and the fragment topology, subject to the following conditions: 1) the intensity of the flow of restoration is constant and equal to 1; 2) the clock nodes function according to the ideal algorithm, that is, there is no influence of the algorithm on the structural reliability.

We set the initial value of the failure rates to be 0.8 with a step change of 0.02. Using a generalized algorithm, we determine the structural constancy of which of the analyzed fragments is higher.

The results of calculations of the dependence of the structural constancy of the fragment of the synchronization network on the failure rate and the fragment topology are shown in Fig. 3.

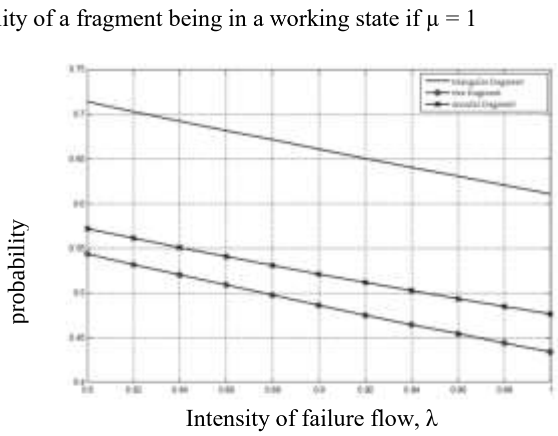


**Fig. 3.** Dependences of the structural constancy of the synchronization network fragment on the failure rate and the fragment topology

Consider an example of using a generalization algorithm to select the optimal topology of a fragment of a synchronization network in some real situations, corresponding to the typical conditions of operation of network synchronization.

Case 1. One of the edges coming from the source has a higher fault tolerance. Increased fault tolerance is ensured by the intracranial location of the rib between the node and the reference source. This situation occurs in many cases in synchronization networks. To choose the optimal topology we use the proposed method. We will select as an edge with high resilience the element at number 6 (Fig. 3.5, 3.9, 3.11 - for a triangular, tree and annular fragment, respectively). Let the intensity of the bounce flow attributed to this element $\lambda_6 = 0.8$, and the intensity of the recovery stream $\mu_6 = 1.0$. For all the last edges, set the initial value of the failure rate to be 0.8 with a step change of 0.02, and the intensity of the recovery stream to be constant and equal to 1.0. Using the proposed generalization algorithm, let's determine how profitable it is to use a particular topology.

The results of the calculation are given in the form of the dependence of structural constancy on the intensity of the failure flow in Fig. 4.

The probability of a fragment being in a working state if $\mu = 1$ and $\lambda_6 = 0.8$

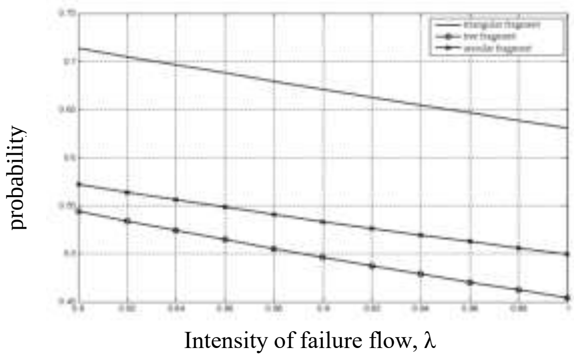


**Fig. 4.** The dependence of structural constancy on the failure rate, if one of the edges has a higher fault tolerance.

Case 2. Two fins from the signal sources have increased fault tolerance. This situation occurs in synchronization networks when using two geographically spaced synchronization signal sources. Increased fault tolerance is ensured by the intracranial location of the rib between the node and the reference source. We choose elements with numbers 6 and 8 as ribs with high fault tolerance (Fig. 3.5, 3.9, 3.11 - for triangular, tree and annular fragment respectively). Let the intensity of the failure flow that these elements account for is $\lambda_6 = 0.8$, $\lambda_8 = 0.8$, and the intensity of the recovery stream $\mu_6=\mu_9=1.0$. For all the last edges, set the initial value of the failure rate to be 0.8 with a step change of 0.02, and the intensity of the recovery stream to be constant and equal to 1.0. Using the proposed generalization algorithm, let us determine how profitable it is to use a particular topology.

The results of the calculation are given in the form of the dependence of structural constancy on the intensity of the failure flow in Fig. 5.

The probability of a fragment being in a working state if $\mu = 1$, ($\lambda_6 = \lambda_8 = 0.8$).

Case 3. All edges from the sources have a slight excess in fault tolerance. This situation occurs, for example, when constructing multi-ring circuits, or at a relative distance of the tree fragment from the source, or when there is a need to synchronize the network from GPS receivers in conditions where there is no guarantee of high reliability of the communication channel due to the distortion of the signal transmitted from the satellite. Then select for the elements $\lambda_6$, $\lambda_8$, $\lambda_9$ = 1.1, and for $\mu_6$, $\mu_8$, $\mu_9$ = 1.0. For all the last edges, set the initial value of the failure rate to be 1.001 with a step change of 0.2, and the intensity of the recovery flow constant to 1.0. Using the proposed generalization algorithm, let us determine how profitable it is to use a particular topology.

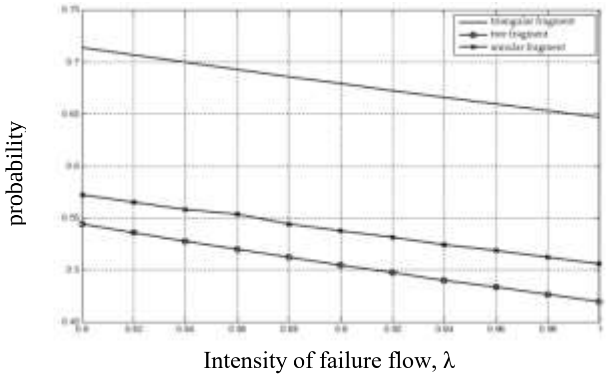


**Fig. 5.** The dependence of structural constancy on the intensity of the failure flow if the two edges have increased fault resistance

The results of the calculation are given in the form of the dependence of structural constancy on the intensity of the failure flow in Fig. 6.

The probability of a fragment being in a working state if $\mu = 1$, $\lambda_4 = \lambda_8 = \lambda_9 = 0.9$

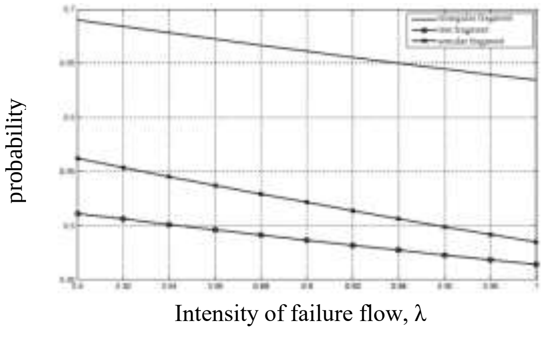


**Fig. 6.** The dependence of structural constancy on the intensity of the failure flow, if all the edges from the sources have a slight excess in failure resistance

In all cases, a fragment with a triangular structure has a higher fault tolerance, also in case 2, the use of a triangular fragment is impractical because the gain on fault tolerance is less than the loss in value.

## 5 Conclusions

A method for determining the stability of network synchronization functioning for each of the fragments of the synchronization network was developed under the given initial conditions: failure rate, recovery rate and initial conditions in which the system was located and taking into account the following parameters: - algorithm of operation of the synchronization node; - a way to set priorities for input interfaces (ports) of synchronization; - establishment of quality levels (quality level) of synchronization signals; is the network fragment topology.

Determined conditions for the loss of performance of the fragment of the network synchronization with the parameters and criteria that define the concept of "performance" and that allows to attribute all possible states of the network fragments to one of two groups: "fragment capable" or "fragment inoperable" in the presence of restrictions in the form independence of the fragment operation from the algorithm of operation of the synchronization node.

The definition of these conditions makes it possible to obtain the value of the theoretical limit of constancy of functioning of the fragment of the synchronization network. The limit value obtained is the maximum in terms of the quality of the network's operation and is called the upper bound. It is to the upper limit that the functional fragment of the network fragment approaches.

A generalized technique for determining the functional capacity for a fragment of a network of synchronization of any topology is developed, which allows:

- to determine the possibility of using these fragments as basic for the construction of a dynamically adaptable synchronization tree;
- determine the values of the parameters on the basis of which it is possible to make the choice of the optimal topology;
- identify options for using promising topological structures.

A comparative analysis of triangular, tree and annular fragments of the synchronization network is carried out in terms of structural stability of the network synchronization in the absence of influence of the algorithm of functioning of the synchronization network node on the structural constancy.

The results of the study showed that in all cases, a fragment with a triangular structure can be used in synchronization networks, because it has a higher fault tolerance, but in some cases the use of a triangular fragment is impractical due to the fact that the gain in fault tolerance is less than the loss in value.

The generalized functionality of synchronization network stability is obtained, which determines the dependence of the reliability of the synchronization network on the functional dependencies between the intensities of failure and recovery flows, network topology, scheduling efficiency, algorithms for the operation of network elements.

## References


1. Alekseev YU.A. y dr. Perspektyvy sozdanyya y razvytyya systemy taktovoy setevoy synkhronyzatsyy v Rossyy // Élektrosvyazʹ. 1995. №12. - S. 5–9.
2. DSTU ITU-T G.811:2008 Merezhi elektrozv'yazku tsyfrovi. Merezhi synkhronizatsiyi. Prystroy isynkhronizatsiyi pervynni. Osnovni tekhnichni kharakterystyky (ITU-T G.811:1997, IDT).
3. Fedorova N.V. Yzmerenye parametrov syhnalov synkhronyzatsyy v setyakh s kommutatsyey paketov// Telekomunikatsiyni ta informatsiyni tekhnolohiyi. - 2014 r. - №1 – S.70-76.
4. Fedorova N.V. Kombynyrovanye metodov obespechenyya synkhronyzatsyey bazovykh stantsyyotraznykh yerarkhycheskykh urovney sety s kommutatsyey paketov / V. Y. Vakasʹ, N.V. Fedorova // 22-ya Mezhdunarodnaya konferentsyya "SVCH-tekhnyka y telekommunykatsyonnye tekhnolohyy". – Sentyabrʹ 2012. – C. 89 – 90.
5. Fedorova N.V. Parametry stabylʹnosty syhnalov synkhronyzatsyy v transportnom okruzhenyy IP/MPLS / N.V. Fedorova, B.M. Byshovets // Rehyonalʹnyysemynar MSÉ dlyastran SNH y Hruzyy “Tendentsyy razvytyya konverhentnykh setey: post -NGN, 4G y 5G”: materyalykonf. (17-18 noyabrya 2016). – Kyev, 2016. – S.135-136.
6. Shklyarevskyy Y. Sputnykovye systemy y sety synkhronyzatsyy. Chastʹ 1. Pryemnyky GPS // Sety y telekommunykatsyy, 2004, № 9. - S. 54-58.
7. Vnedrenye MNP v Ukrayne. Retrieved from: http://internetua.com/vnedrenie-MNP-v-ukraine-okazalos-v-slojnom-polojenii
8. QoS-aware Middleware for Web Services Composition/ Zeng L., Benatallah B., et al // IEEE Transactions on Software Engineering, Vol. 30, No. 5, 2004, pp. 311–327.
9. ITU-T Recommendation E.802. Series E: Overall network operation, telephone service, service operations and human factors – Framework and methodologies for the determination and application of QoS parameters. Geneva: International Telecommunications Union. – 2007.
10. ITU-T Recommendation G.1000. Series G: Transmission systems and media, digital systems and networks. – Communications quality of service: A framework and definitions. Geneva: International Telecommunications Union. – 2002.
11. Khlaponin Y. Proportional allocation method of the required bandwidth capacity for the user stations using the LTE technology / Khlaponin Y., Al-Zayadi Haider, Al-Sharify Mushtaq Talib, AL-Sharify Talib, Karpinski M. // Technical Transactions: Electrical engineering. (Czasopismo techniczne: Elektrotechnika), 2016 – № 2-E – P. 203 – 212. – ISSN 2305-9397 http://suw.biblos.pk.edu.pl/resourceDetailsRPK&rId=63508
12. Lavrov E. Mathematical models for the distribution of functions between the operators of the computer-integrated flexible manufacturing systems / Lavrov, E., Pasko, N., Krivodub, A., Tolbatov, A. / 2016 Modern Problems of Radio Engineering, Telecommunications and Computer Science, Proceedings of the 13th International Conference on TCSET 2016 – Lviv-Slavske, 2016. – P. 72–75.

13. Tolbatov A. Theoretical bases, methods and technologies of development of the professional activity analytical estimation intellectual systems / Zaritskry, O., Pavlenko, P., Sudic, V., Tolbatov, A., Tolbatova, O., Tolbatov, V., Tolbatov, S., Viunenko, O. / 2017 2nd International Conference on Advanced Information and Communication Technologies, AICT 2017 – Proceedings – Lviv, 2017. – P. 101–104.
14. Hryshchuk R., Molodetska K., Syerov Y. Method of Improving the Information Security of Virtual Communities in Social Networking Services. CEUR Workshop Proceedings. 2019. Vol 2392: Proceedings of the 1st International Workshop on Control, Optimisation and Analytical Processing of Social Networks, COAPSN-2019. p. 23–41.
15. Gnatyuk S. Ergonomic Support for Decision-Making Management of the Chief Information Security Officer / Sergiy Gnatyuk, Nataliia Barchenko, Olena Azarenko, Andrii Tolbatov, Victor Obodiak, Volodymyr Tolbatov / 1st International Conference on Cyber Hygiene and Conflict Management in Global Information Networks (CyberConf 2019) Lviv Ukraine, November 29, 2019. – P. 459–471.
16. Molodetska K., Brodskiy Yu., Fedushko S. Model of Assessment of Information-Psychological Influence in Social Networking Services Based on Information Insurance. CEUR Workshop Proceedings. Vol 2616: Proceedings of the 2nd International Workshop on Control, Optimisation and Analytical Processing of Social Networks (COAPSN-2020), Lviv, Ukraine, May 21, 2020. p.187-198. http://ceur-ws.org/Vol-2616/paper16.pdf
17. R. Odarchenko, V. Gnatyuk, S. Gnatyuk, A. Abakumova, Security Key Indicators Assessment for Modern Cellular Networks, Proceedings of the 2018 IEEE First International Conference on System Analysis & Intelligent Computing (SAIC), Kyiv, Ukraine, October 8-12, 2018, pp. 1-7.
18. Z. Hassan, R. Odarchenko, S. Gnatyuk, A. Zaman, M. Shah, Detection of Distributed Denial of Service Attacks Using Snort Rules in Cloud Computing & Remote Control Systems, Proceedings of the 2018 IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control, October 16-18, 2018. Kyiv, Ukraine, pp. 283-288.