Study on Complex Assessment of the Information and Communication Systems Efficiency

Sergii Ye. Gnatiuk [1][0000-0002-1541-7058], Lev Sakovych [1] [0000-0002-8257-7086], Yaroslav Evchenko [1] [0000-0141-2256-8798], Valerii Yakovliev [2] [0000-0001-5261-4432], Tetiana Okhrimenko [3] [0000-0001-9036-6556] and Aleksei Klochkovskii [3] [0000-0002-7431-1106]

[1] Institute of Special Communications and Information Security, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
[2] Sumy National Agrarian University, Sumy, Ukraine
[3] National Aviation University, Kyiv, Ukraine
gnatyk-2@i.ua, lev@sakovich.com.ua

Abstract. Evaluation of the communications system efficiency is a multi-criteria problem of determining the real state of various components of its functioning quality. The formalization of the complex estimation of efficiency, taking into account the influence on its value of separate quality indicators, is suggested. Scientific novelty of the work consists in quantitative estimation of the individual components probabilistic indices value and a comprehensive assessment of the communications system functioning quality in general. The obtained results should be used both during the evaluation of the effectiveness of existing and with the reasonable choice of the development of perspective communications systems.

Keywords: information and communications system, complex assessment, functioning efficiency, security.

1 Introduction

Improving the communications systems (CS) functioning in the modern conditions of their development is one of the urgent scientific and practical problems. Particular attention is paid to the problem of quantifying the effectiveness of these systems functioning, and not on individual indicators, but in a complex way, taking into account the influence of all indicators of quality on the result of the system's intended use.

2 Analysis of literature

In recent years, scientific research has been carried out on the quantitative assessment of the quality of compliance with certain requirements for the use of CS. In [1] the principles of constructing modern CS are formulated and the requirements for them are defined, but there are no recommendations for the quantitative assessment of quality indicators. In [2-5] the prospective directions of the CS development are determined taking into account the experience of the advanced countries of the world. In [6-10], recommendations are given for assessing the reliability of particular samples of communications technology (CT), as well as reliability and survivability of CS as a whole. In [11-15] the issues of diagnostic improvement were considered, and in [16, 17] - the metrological maintenance of the repair of CT. However, the previous studies were not systematic, but solved partial tasks. The analysis of works devoted to methods of estimating the efficiency of CS shows that not all of them are widely practically used, are not always optimal, do not take into account the specifics of the CT operation in real conditions.

3 The purpose of the article

To make the process of integrated assessment of the effectiveness of the CS and to demonstrate formal, on the example of the observance of the requirements for reliability and readiness, the opportunity to streamline actions for its estimation with the calculation of probabilistic quality indicators.

4 The main material

Communications and automation system is a set of interconnected, compatible and subsystem-driven tasks that meet such requirements [1]:

- high readiness for intended use – the ability of the CS at any time and in any circumstances to fulfill the tasks of ensuring the exchange of information among users;
- stability – the ability of CS to perform tasks for its intended purpose under the influence of all the impressive factors (characterized by survivability, noise immunity and reliability of CS);
- mobility – the ability of the CS to be deployed within the established time frame, to change the topology and capabilities in accordance with the conditions of the situation;
- bandwidth – the ability of the CS to provide the flow of information services per time unit with a given quality;
- security – the ability of CS and automation to provide protection against unauthorized access and imitation stability;
- interoperability – the ability of CS and automation to ensure the interoperability of telecommunications and automation systems with other systems without additional couplings and additional software.

Nowadays, there is no single methodology for a comprehensive assessment of the satisfaction of these requirements for CS, which makes it difficult to assess the effectiveness of existing ones and justify the choice of rational options for their further development. It is most accessible to quantify the compliance of the CS with the requirements for reliability, readiness, mobility and bandwidth due to the criteria set by the guidance documents, but as the communications systems are developing they also need to be scientifically substantiated [6-10].

The solution of the problem of CS efficiency complex estimation is expedient to perform in the following sequence (Fig. 1):

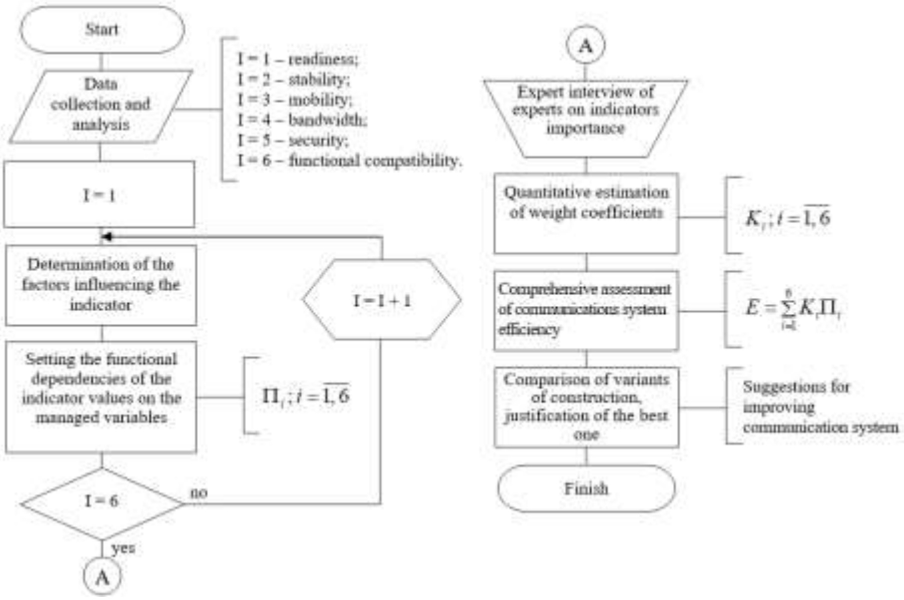

Fig. 1. Block diagram of the communications system efficiency complex estimation algorithm

As a result of the source data collection and analysis, determine the factors affecting the quality indices of the CS and establish the functional dependencies of these indicators values on the managed variables for obtaining the normed values of the quantitative assessment of compliance (Π_i).

The expert survey of leading specialists in the organization of communications quantitatively assess the weighting factors of all indicators of quality CS (K_i).

Carry out a comprehensive assessment of the effectiveness of the CS in the form of a quantitative assessment of the likelihood of its compliance

$$0 < E = \sum_{i=1}^{6} K_i \Pi_i \le 1 \text{, where } 0 \le \Pi_i \le 1;\ 0 < K_i < 1;\ \sum_{i=1}^{6} K_i = 1;$$

as a result of ranking according to the degree of reduction of the value of E to determine the most promising options for the development of CS.

One of the most important indicators of the CS quality is reliability, without which their use is meaningless. Let us consider the possibility of a formalized assessment of this requirement for CS.

The property of CS reliability consists in the ability to provide a connection with the maintenance of the performance indicators values, which are set by the requirements set by the requirements, which are supported by the subsystem of the technical support of communications with the fulfillment of all kinds of the CT repair, maintenance and provision with consumable materials.

Traditionally, as the main indicator of reliability of CS, a readiness factor A_c [18] is used, which represents the probability of technical reliability of all CT facilities and the readiness to operate in the full range of all communications lines. However, for a more objective feature of the CS is the probability of a system's technical readiness for the exchange of information between subscribers at least in one direction of communication P_c, which in the literature on the theory of reliability is defined as the probability of connection or the probability of a working state of at least one of the possible connection directions:

$$P_c = 1 - \prod_{j=1}^{S} \left(1 - A_j\right),$$

where A_j – is readiness factor of the j-th direction of communications, S – is number of communications directions between subscribers in CS. This expression quantifies the upper limit of network reliability, and the values of the lower limit are calculated according to [19] by the expression:

$$P_{сн} = \prod_{j=1}^{S} \left(1 - U_j\right) = \prod_{j=1}^{S} A_j ,$$

where $U_j = 1 - A_j$ – is unattended rate of the j-th direction of communications. Approximate estimation methods of Ezari-Proshan and Polissky are used to simplify calculations, which are reduced to the consideration of incomplete connecting and unconnected events, which are determined by lower estimates [18].

The objective estimation of the quality of the CS must take into account, in addition to the probability of the connection, the value of the "erlang" losses p, due to the occupancy of the channels during t time of carrying out the task of the message transmition. Then the complex indicator of the reliability of the communications direction takes the form [20]:

$$W_j = 1 - \prod_{j=1}^{S} \left[1 - A_j \left(1 - p_j\right) \exp\left(-\frac{t}{T_j}\right)\right],$$

where T_j – is workout on the refusal of the CT that forms the path j.

Obviously, that $W_j < P_c$, because P_c quantifies the potential structural reliability of the CS. It follows that when switching channels, it is expedient to use as a criterion for choosing a path indicator [20]:

$$V_j = \frac{W_j}{r_j};\ j = \overline{1, m};$$

where r_j – is number of receivers of the communications direction j with m possible.

Directions of communications are chosen as the value of this indicator decreases, and the advantage is always given to a more reliable, least loaded with a minimum number of reciprocalties, which allows to improve the management efficiency of the topology of the CS [21].

In this case, as a normalized index of the reliability of CS it is advisable to use the value P_c, obtained for the block diagram of Fig. 2 after the analysis of the CS topology, the composition of its CT and the requirements for the minimum acceptable probability of connectivity P_{cn},

where n_j – number of CT directions j. That is, the normalized stability value is quantified as $\Pi_2 = P_c$.

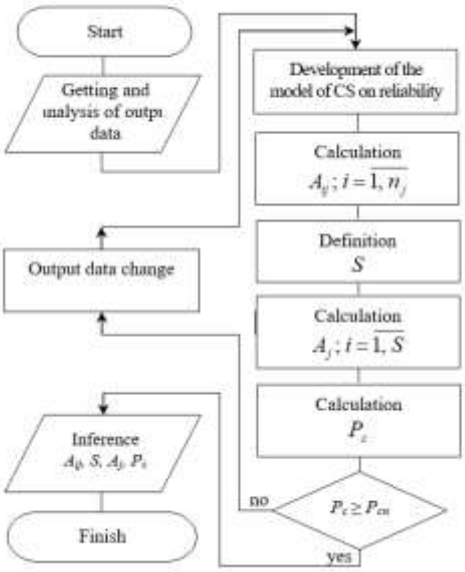

Fig. 2. Block diagram of the algorithm for calculating the connection probability of the communications system

Let us consider the possibility of formalizing the quantitative assessment of the value of one of the basic requirements for CS – readiness for use, which depends on the personnel training, the technical condition of the CT, and technical, diagnostic and metrological support. It is possible to quantify this during the control of the technical support of communications in order to study thoroughly the state of the CT and the organization of the personnel work.

The sequence of actions of the first stage is formalized in the form of graphic diagrams of fig. 3, and a list of relevant operations is given in Table 1, which takes into account the factors that influence the readiness of individual CT samples.

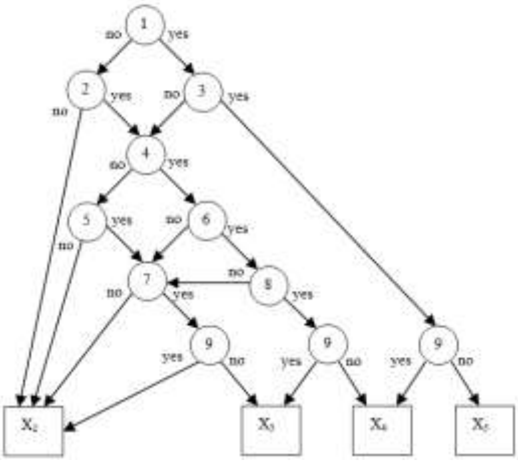

Fig. 3. Graphic diagram of the operations algorithm for assessing the technical condition of communications means samples

A comprehensive assessment of the CS availability is a step-by-step process:

- at the first stage quantitatively assess the technical state of individual CT samples;
- then receive a quantitative estimation of the communications hardware (CH) technical condition, which takes into account the factors affecting the readiness quality;
- further evaluate the technical condition and readiness for use by the appointment of the communications equipment group of the same type at the signal center;
- at the final stage, receive a comprehensive assessment of the readiness of the signal center, depending on its purpose.

Graphic diagram of the presentation of the CT state assessing process (Fig. 3) allows, using the mathematical apparatus of logic algebra, considering possible options for assessing the technical condition:

$$X = X_5 \vee X_4 \vee X_3 \vee X_2 = \bigvee_{i=2}^{5} X_i;$$

$$X_5 = x_1 x_3 \overline{x_9};\; X_4 = x_1 x_3 x_9 \vee x_1 \overline{x_3} x_4 x_6 x_8 \overline{x_9} \vee \overline{x_1} x_2 x_4 x_6 x_8 \overline{x_9};$$

$$X_3 = x_1 \overline{x_3} x_4 x_6 x_8 x_9 \vee \overline{x_1} x_2 x_4 x_6 x_8 x_9 \vee \overline{x_1} x_2 x_4 \overline{x_6} x_7 \overline{x_9} \vee \overline{x_1} x_2 x_4 x_6 x_7 \overline{x_8}\,\overline{x_9} \vee \overline{x_1} x_2 \overline{x_4} x_5 x_7 \overline{x_9};$$

$$X_2 = \overline{x_1}\,\overline{x_2} \vee \overline{x_1} x_2 \overline{x_4}\,\overline{x_5} \vee \overline{x_1} x_2 \overline{x_4} x_5 \overline{x_7} \vee \overline{x_1} x_2 \overline{x_4} x_5 x_7 x_9 \vee \overline{x_1} x_2 x_4 x_6 \overline{x_7}\,\overline{x_8} \vee \overline{x_1} x_2 x_4 x_6 x_7 \overline{x_8} x_9;$$

where X – CT technical condition;

X_i is technical condition assessment $\left(i = \overline{2, 5}\right)$;

x_i is positive assessment of the operation and of the Table 1;

$\overline{x_i}$ is negative assessment of the operation and of the Table 1.

Table 1. List of operations for assessing the technical condition of communications means samples

Conditional number	Contents of the operation
1	The sample is functional, ZIP-0 is complete, the documentation is correct, the electrical safety equipment is working.
2	The sample is workable, complete with components, ready for use.
3	Timely and qualitatively full maintenance.
4	The complete set of ZIP-0 is not less than 50% of each nomenclature and instrument is not less than 85%.
5	Completeness of ZIP-0 is not less than 50% of each nomenclature and instrument is not less than 75%.
6	The value of the parameters are brought to the standards by the crew by means of regulation in the process of checking the sample.
7	Detected disadvantages are removed by the crew with the involvement of repair body specialists and using the ZIP-0 not later than in 4 hours.
8	Detected disadvantages are removed by the crew using ZIP-0 not later than in 1 hour.
9	Broken up to 20% of subscriber tracks or the same type of products, there is no connection inside the signal center, measuring instruments are not approved.

This is necessary to quantify the quality indicators of the process of determining the state of CT.

Let us consider the possibility of quantitative estimation of the mathematical expectation (ME) of the deviation of the evaluation of the technical state of the CT specimen from the actual one in the presence of one error in determining the result of the operation of Table 1 on the example of the evaluation "good". According to [22], the ME of the discrete value is equal to the sum of the product of the value of the random variable on the probability of its appearance. In this case we receive:

- the error in the first step does not affect the result;
- the error in the second step (operation 2) gives the largest deviation of the assessment of the state of the CT, which is equal to $2(1-p)p$;
- errors in other steps lead to a rejection of the assessment of the CT state on $(1-p)p^5$; where p – the probability of a correct assessment of the operation result of Table 1.

Similarly, we obtain the ME deviation of the estimation for all possible cases, if that probability of correct estimation of the results of all operations is the same and equal to p:

$$\rho_2 = 2(1-p)p^2 + 2(1-p)p^5 = 2(1-p)p^2(1+p^3);$$

$$\rho_3 = (1-p)p^5 + (1-p)p^5 + (1-p)p^5 + (1-p)p^5 + (1-p)p^5 = 5(1-p)p^5;$$

$$\rho_4 = 2(1-p)p + (1-p)p^5 + (1-p)p^5 + (1-p)p^5 = (2+3p^4)(1-p)p;$$

$$\rho_5 = (1-p)p^5 + (1-p)p^4 + (1-p)p^2 = [p^2(p+1)+1](1-p)p^2.$$

The minimum value of the probability of a correct assessment of the state of the CT is obtained with the maximum number of inspections:

$$P_5 = p^3;\ P_4 = p^6;\ P_3 = P_2 = p^7.$$

The results are shown in Fig. 4 and 5. Let us consider the requirements for the meaning p of the conditions $P \geq 0{,}9$ and $\rho \leq 0{,}5$:

$\rho_4 = (2 + 3p^4)(1 - p)p \leq 0{,}5$ – solution exists for $p \geq 0{,}8$;

$P_3 = p^7 \geq 0{,}9$ – solution exists for $p \geq 0{,}988$.

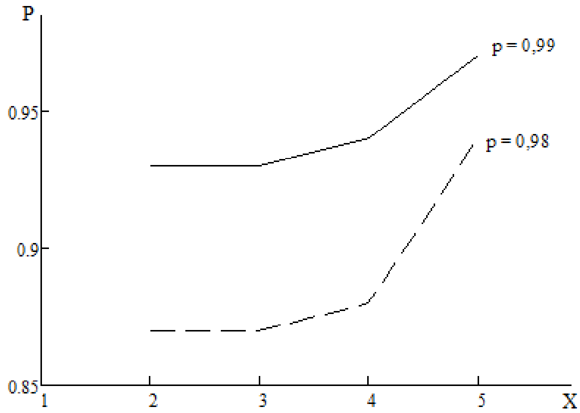

Fig. 4. Dependences of the minimum value of the correct estimation probability of special communications means samples conditions.

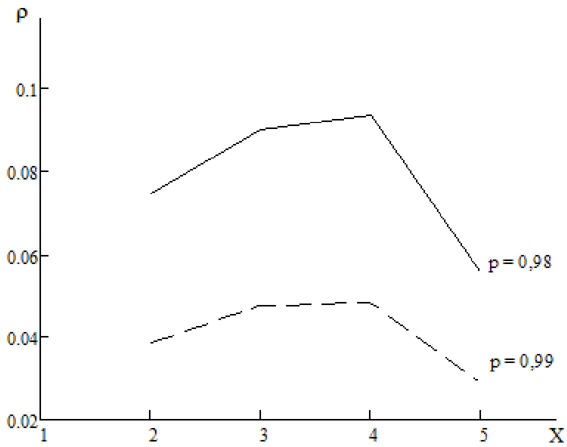

Fig. 5. Dependences of mathematical expectation of estimation deviation of special communications means samples.

Performing operations in Table 1 requires the simultaneous evaluation of several logical conditions. It is known that the probability of making the correct decision under several logical conditions is [23,24]:

one, two	$p = 0{,}995$;
three, four	$p = 0{,}950$;
five and more	$p = 0{,}900$;

which corresponds to the results obtained.

Using the obtained results to evaluate the technical condition of individual CT samples, personnel training, technical and metrological maintenance of their operation allows us to formalize the process of assessing the technical state of the CA as a whole (Fig. 6).

An assessment of the technical state of individual CA allows us to further assess the technical condition of a group of the same type of equipment. All CT is subdivided into *n* 15 groups, the order of assessment of which is shown in Fig. 7, where n_i – is the number of tested CAs that received an assessment $X_i = \overline{2,5}$; N - is total number of samples of equipment in the group; z_i – is percentage of CA that received an assessment i; Z – general assessment of a group of the same type of communications means.

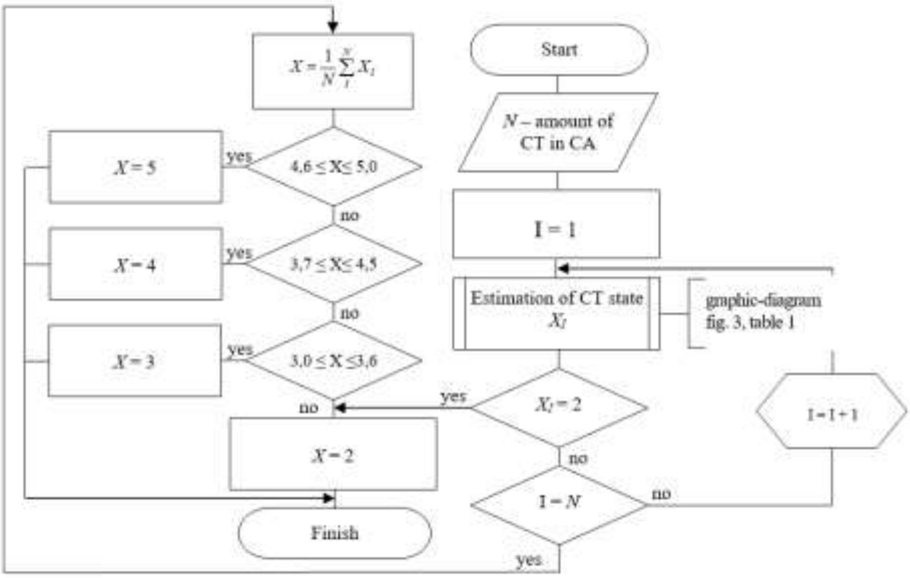

Fig. 6. Block diagram of the algorithm for evaluating the technical state of the hardware communications

At the final stage of the assessment of the signal center readiness, take into account the number of well-trained and functioning CT, which received positive assessments ($Z > 2$) by groups.

According to the requirements, the communication node is ready for use, if the ratio of a decent and functioning CT to its full-time number for the main groups is $\eta_o \geq 0{,}75$ and for the non-core groups is $\eta_н \geq 0{,}5$. In assessing the readiness of the

CS, it is advisable to compare them to the obtained values η_o, which in the future is equal to Π_1 according to Fig. 1, and inequality $\eta_u \geq 0{,}5$ use as a constraint. Thus, the approach taken in this work allows to objectively and comprehensively evaluate the degree of readiness of signal centers during verification.

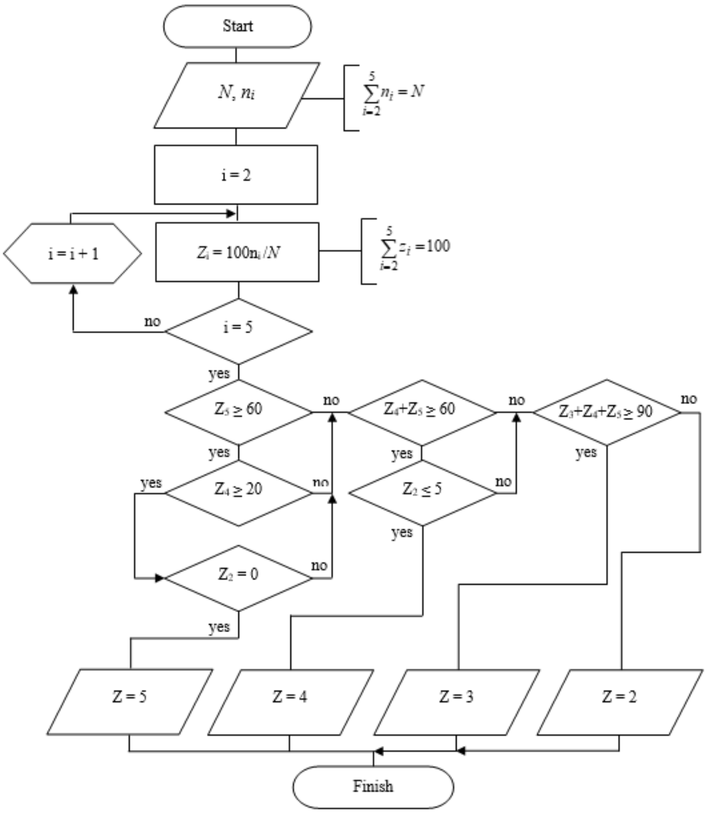

Fig. 7. Block diagram of the algorithm for evaluating the technical condition of groups of the same type communications means

5 Conclusions

In the article, based on the analysis of known methods for assessing the effectiveness of the CS, taking into account the requirements of the guidance documents, formalized the procedure for checking compliance with valid requirements.

On the example of quantitative assessment of reliability and readiness of CS, for the first time, the possibility of realization of the suggested stages of evaluation with the definition of probabilistic indicators of the results obtained, in which the scientific novelty and the difference from the known works, is considered for the first time.

The further tasks of the study are to determine the factors affecting other quality indicators of CS and to establish the functional dependencies of the values of these indicators from the controlled variables, as well as conducting an expert survey of leading specialists in the field of communications organization and quantify the values of the weight coefficients of the individual quality indices of CS.

The implementation of these tasks allows us to obtain a comprehensive assessment of the effectiveness of the CS.

References

1. A. Tikhomirov, N. Kinash, S. Gnatyuk, A. Trufanov, O. Berestneva et al, Network Society: Aggregate Topological Models, Communications in Computer and Information Science. Verlag: Springer International Publ, Vol. 487, pp. 415-421, 2014.
2. Edward Golan, Adam Kraśniewski, Janusz Romanik, Paweł Skarżyński, Robert Urban, "Experimental Performance Evaluationof the Narrowband VHF Tactical IP Radioin Test-Bed Environment", Military Communications and Information Technology: A Trusted Cooperation Enabler, vol. 2, pp. 99-106, 2012.
3. United States. Joint Chiefs of Staff, Defense Technical Information Center (DTIC). Joint Publication 6-0: Joint Communications System (2018, June 10). [Online]. Available: http://www.dtic.mil/doctrine/new_pubs/jp6_0.pdf
4. Mazin Al Hadidi, J. Samih Al-Azzeh, O. Tkalich, R. Odarchenko, S. Gnatyuk, Yu. Khokhlachova. ZigBee, "Bluetooth and Wi-Fi Complex Wireless Networks Performance Increasing", International Journal on Communications Antenna and Propagation, Vol. 7, № 1, pp. 48-56, 2017.
5. Signal battalion recognized for outstanding support, The Maple Leaf, 28 September 2007, Vol. 10, No. 6.
6. Mazin Al Hadidi, Jamil S. Al-Azzeh, R. Odarchenko, S. Gnatyuk, A. Abakumova, Adaptive Regulation of Radiated Power Radio Transmitting Devices in Modern Cellular Network Depending on Climatic Conditions, Contemporary Engineering Sciences, Vol. 9, № 10, pp. 473-485, 2016.
7. Kharybin A.V. About the approach to the decision of questions of a choice of methodology of an estimation of system reliability and survivability of information systems of critical application / A.V. Kharybin, O.N. Odaryshchenko // Radiotechnical and computer systems. – Kh.: NAU "KhAI". – 2006. – № 6(18). – pp. 61–70.
8. Holovan' S.M. The basis of the information systems / S.M. Golovan', O.V. Korneyko, O.S. Petrov, V.O. Khoroshko, L.M. Shcherbak. – Lugans'k: "Naulídzh" Publ., 2012. – 335 p.
9. Volochiy B.Y. System engineering design of telecommunication networks / B.Y. Volochiy, L.D. Ozirovskii. – Lviv: Lviv Polytechnic Publ., 2012. – 128 p.
10. Z. Hu, V. Gnatyuk, V. Sydorenko, R. Odarchenko, S. Gnatyuk, "Method for Cyberincidents Network-Centric Monitoring in Critical Information Infrastructure", International Journal of Computer Network and Information Security, Vol. 9, № 6, pp. 30-43, 2017.
11. Yanliang Li, Rui Kang, Lin Ma, Lei Li. Application and improvement study on FMEA in the process of military equipment maintenance . 9th International Conference on Reliability, Maintainability and Safety, 12-15 June 2011, Guiyang, China: Proc. IEEE, 2011, Vol. I, II, pp. 803–810. — DOI: http://dx.doi.org/10.1109/ICRMS.2011.5979402.
12. Robert Thomson, John Lynn. The benefits of using head mounted displays and wearable computers in a military maintenance environment . 2010 International Conference on Education and Management Technology (ICEMT), 2-4 November 2010, Cairo, Egypt: Proc. IEEE, 2010, pp. 560–564. — DOI: http://dx.doi.org/10.1109/ICEMT.2010.5657592.

13. Haikuan Wang, Quan Shi, Fei Xiong, Kan Wang. The application of TOPSIS on sequencing decision-making in equipment battlefield repair. 2013 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering (QR2MSE), 15-18 July 2013, Emeishan, Sichuan, China: Proc. IEEE, 2013, Vol. II, pp. 1574–1578. — DOI: http://dx.doi.org/10.1109/QR2MSE.2013.6625876.
14. Chunliang Chen, Wenhua Shi, Shixin ZhangThe key operation ascertaining of armored equipment parts batch-repair progress for quality monitoring based on FCE. 2013 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering (QR2MSE), 15-18 July 2013, Emeishan, Sichuan, China: Proc. IEEE, 2013. Vol. II, pp. 1542–1545. — DOI: http://dx.doi.org/10.1109/QR2MSE.2013.6625867.
15. Al-Azzeh J.S., Al Hadidi M., Odarchenko R., Gnatyuk S., Shevchuk Z., Hu Z. Analysis of self-similar traffic models in computer networks, International Review on Modelling and Simulations, № 10(5), pp. 328-336, 2017.
16. UddE. Application of Fiber Optic Smart Structures // Opt. and Photon News. – 1996. Vol. 7, № 5. – P. 17–22.
17. Senior J. M. Moss S.E., Cusworth S.D. Multiplexing Techniques for Noninterferometric Optical Point-Sensor Networks // Fiber and Integr. Opt. 1998. – Vol. 17, № 1. – P. 3–20.
18. Reliability of technology. Terms and definitions: DSTU 2860–94. – [Valid from 1995-01-01]. – K. : State standart of Ukraine, 1995. – 90 p. – (National standart of Ukraine).
19. Popovskii V.V. Methods of a priori evaluation of network reliability / V.V. Popovskii, V.S. Volotka // Radio engineering. – Kharkiv : KhNUR, 2014. – Vol. № 178. – pp. 20–23.
20. Rizhakov V.A. Quantitative assessment of the structural reliability of communication systems / V.A. Rizhakov, L.M. Sakovych // Communication. 2004. № 4. pp. 53–57.
21. Mynochkyn A.Y. Managing the topology of a mobile radio network / A.I Minochkin, V.A. Romaniuk // Communication. 2003. № 2. pp. 28–33.
22. Z. Hu, S. Gnatyuk, O. Koval, V. Gnatyuk, S. Bondarovets, «Anomaly Detection System in Secure Cloud Computing Environment», International Journal of Computer Network and Information Security, Vol. 9, № 4, pp. 10-21, 2017.
23. Fedushko S., Ortynskyy V., Reshota V., Tereshchuk V. Legal And Economic Aspects of the PR Campaign of Scientific Conference in Social Networks. CEUR Workshop. Vol 2616: COAPSN-2020, 2020. p. 342-352. http://ceur-ws.org/Vol-2616/paper29.pdf
24. 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: COAPSN-2019. p. 23–41.
25. L.M. Sakovych. Selection of measuring tools for maintenance and ongoing repair of equipment for information security systems / L.M. Sakovych, V.V. Ryzhakov, V.P. Pavlov // Legal, normative and metrological provision of information security systems in Ukraine. –K: NTUU “KPI”, 2003. – Vol. № 7. – pp. 77–85.