UDC 621.39(045)
DOI:10.18372/1990-5548.88.20976

[1]Serhii Tarasiuk,
[2]Georgiy Konakhovych,
[3]Oleksandr Bondarev,
[4]Maksym Zaliskyi

ASSESSMENT OF QOS METRICS IN AVIATION COMMUNICATION NETWORKS

Department of Telecommunication and Radio Electronic Systems, Faculty of Air Navigation Electronics and Telecommunications, State University "Kyiv Aviation Institute", Kyiv, Ukraine
E-mails: [1]7619224@stud.kai.edu.ua ORCID 0009-0007-9659-9634,
[2]heorhii.konakhovych@npp.kai.edu.ua ORCID 0000-0002-6636-542X, [3]alexbondarev1990@gmail.com
ORCID 0009-0006-5391-8829, [4]maximus2812@ukr.net ORCID 0000-0002-1535-4384

Abstract*—An important factor in providing safety in aviation is the reliable operation of radio communication systems. These systems gives possibility to transmit necessary information during flights and the performance of aviation operations, in particular for air traffic control, as well as take-off and landing processes. These systems are aimed at meeting the needs of aviation companies and enterprises. Radio communication facilities have certain parameters that determine their effectiveness in terms of purpose, technical level, economic feasibility, reliability, and operational characteristics. A separate group of these parameters describes the quality of service. This article examines the characteristics of aviation radio communication systems in terms of their ability to meet the needs of users of air navigation services. The authors analyze a generalized list of service quality indicators, and also describe approaches to their calculation and modeling. Particular attention is paid to reliability indicators, analysis of relevant models and the specifics of data processing to determine their quantitative values. The obtained results can be used by aviation industry specialists during the operation of radio communication systems.*

Keywords—Radio communication systems, quality of service, reliability, operation, telecommunications network.

I. INTRODUCTION

Modern telecommunications infrastructure includes a set of hardware, software and organizational tools designed to perform the functions of transmitting, processing, storing, and ensuring the protection of information for a particular enterprise. The telecommunications infrastructure includes:

- telecommunications network equipment (switches, wireless access points, switches, and others);
- information transmission channels (wired, wireless, and optical);
- server equipment and data hubs;
- software platforms for managing telecommunications infrastructure;
- equipment and network status monitoring systems;
- quality of service assurance systems.

An important element in the analysis of telecommunications infrastructure is the selection of the correct protocols for data exchange and communication of various components of this infrastructure.

The basic component of corporate telecommunications infrastructure is server equipment that interacts with other components. The infrastructure has a multi-level hierarchical structure. We can consider the access layer, the aggregation layer, and the network core. In this case, the flexibility, fault tolerance and scalability of the entire infrastructure can be ensured. The access layer serves to connect user devices, such as personal computers, Internet of Things (IoT) devices, etc. At the aggregation layer, traffic concentration and pre-processing are provided. The network core performs the functions of high-speed transmission of large datasets between various components of the telecommunications infrastructure. Today, network function virtualization (NFV) technologies and the use of software-defined networks (SDN) are also becoming increasingly widespread, which generally allows centralized management of available resources and timely adaptation to a changing environment.

II. LITERATURE REVIEW

An important element of the infrastructure of civil aviation is radio equipment, which ensures the functioning of key processes in the industry [1]. It is used to receive and process radar and radio navigation information, which is necessary for the orientation of aircraft in the airspace. This equipment also provides the transmission and reception of voice messages, which are used for the coordination and control of flights, increasing the efficiency and safety of aviation activities.

Providing an appropriate level of quality of service (QoS) involves achieving a balanced ratio between the functionality of the aviation radio communication system, perceived by the user, and the costs associated with the acquisition, implementation and further operation of the equipment [2], [3]. The efficiency of the equipment is determined not only by its technical characteristics, but also by the economic feasibility of its use.

Achieving the required level of security of transmitted information is based on an integrated approach, which includes the use of modern software and hardware means of information protection together with the implementation of appropriate organizational and administrative measures. Such an integrated system is aimed at ensuring the confidentiality, integrity and availability of information, as well as increasing the noise immunity of the communication channel under the influence of external and internal factors.

The article [4] presents a generalized analysis of approaches to ensuring QoS and quality of experience (QoE) in information-centric networks. The research covers the systematization of modern solutions and mechanisms for managing the quality of services, which contributes to a deeper understanding of the principles of their functioning. The authors consider existing models and protocols, focusing on their strengths and weaknesses in practical application. Considerable attention is paid to the interdependence between objective technical indicators of quality of service and subjective user perception. As a result, the research is valuable for the scientific and engineering community, as it outlines the current directions for QoS development.

The publication [5] considers an approach to quality of service management based on user request orientation in next-generation networks. The study uses the concept of intent-based networking, which allows to automatically configure network settings in accordance with defined goals and policies. The proposed method is aimed at coordinating the technical parameters of the network infrastructure with the expected level of service from users. Also, considerable attention is paid to the issues of dynamic adaptation and optimization of QoS parameters depending on changes in network operating conditions. As a result, the work has practical value, as it offers effective solutions for improving the quality of service in intelligent telecommunication systems.

The article [6] examines the possibilities of using machine learning algorithms to analyze and predict the quality of perception of telecommunication services by users. The study proposes an approach to classifying QoE levels based on a set of network operating parameters and behavioral characteristics. A comparative analysis of different machine learning models is conducted to determine their ability to accurately predict changes in the perception of service quality. Special emphasis is placed on the concept of sustainable QoE, which involves ensuring a stable level of user satisfaction in long term. The results confirm the effectiveness of intelligent approaches to improving the quality management of telecommunication services.

The study [7] presents a generalized overview of the criteria used to assess the quality of service in integrated passenger transport systems. The paper structures the main indicators used to analyze the efficiency of transport services from the point of view of the end user. It is emphasized that the quality in such systems is complex and depends on the coordinated interaction of different modes of transport in a single transport network. Approaches to measuring and comparative assessment of QoS parameters in different components of the transport infrastructure are also considered. As a result, the authors form a systematic understanding of the key criteria for the quality of service that can be used to improve the management and planning of passenger transport systems.

The study [8] considers the assessment of quality of service indicators within the framework of a traffic engineering model for next-generation wireless sensor networks. The article is aimed at analyzing key QoS characteristics, in particular, transmission delay, throughput, and packet loss, which determine the efficiency of the network. The authors investigate the impact of various traffic management mechanisms on the performance and stability of data transmission in sensor networks. Separately, approaches to the optimal use of network resources to maintain the required level of quality of service under variable load conditions are considered.

The studies [9], [10] consider different approaches to improving the quality of service in computer networks. In the article [9], the main attention is paid to managing network traffic in local networks to prevent overloads and ensure stable system operation. In the paper [10], the use of the clustering method is proposed to optimize QoS parameters and increase the efficiency of network resource allocation. Both approaches are aimed at increasing the performance and reliability of network services through various management mechanisms. To improve the QoS, it is possible to use different machine learning tools [11].

The review of scientific publications demonstrates that ensuring QoS is a multifactorial problem that covers telecommunication, transport and information systems and depends on technical, organizational and user parameters. It is generally established that modern approaches to improving QoS are based on the use of intelligent methods of management, modeling and optimization of network resources, which allows adapting systems to dynamic operating conditions and improving the QoS for end users.

III. PROBLEM STATEMENT

The functioning of modern aviation communication systems is primarily focused on meeting the needs of aviation enterprises and airlines, including supporting safe and effective air traffic control. Such systems play a critically important role in transmitting information necessary for flight coordination, route maintenance, and ensuring interaction between ground services and aircraft. At the same time, telecommunications equipment is characterized by a set of heterogeneous parameters that determine its effectiveness in various aspects: functional purpose, technical level, throughput, economic feasibility, reliability of operation, and operational stability in real conditions. Each of these indicators reflects individual aspects of the quality of system operation and affects the overall level of its productivity.

The purpose of this study is to analyze the possibility of using individual technical and operational parameters as QoS indicators. Their potential for assessing the efficiency of communication systems and the feasibility of integrating such characteristics into general models of quality of service management in aviation telecommunications networks will also be considered. Mathematically, the problem can be stated as follows. Let Θ is an integral QoS parameter. It depends on tactical ϑ and technical δ parameters of equipment, reliability parameters λ, operation parameters ω, economic parameters ν, and other parameters ρ. In general, QoS parameter is a function $\Theta\{\vartheta,\delta,\lambda,\omega,\upsilon,\rho\}$. For these parameters, there are requirement of consumer $R\{\vartheta,\delta,\lambda,\omega,\upsilon,\rho\}$. If the level of consumer satisfaction is L, then it is necessary to solve optimization problem:

$$\max L\big(\Theta\{\vartheta,\delta,\lambda,\omega,\upsilon,\rho\}-R\{\vartheta,\delta,\lambda,\omega,\upsilon,\rho\}\big). \quad (1)$$

Therefore, it is necessary to maximize consumer satisfaction by getting close coincidence between QoS parameters and corresponding requirements.

IV. PROPOSED METHOD

The services for aviation radio communication can be described through a set of various characteristics that reflect their value to users and the effectiveness of their utilization. If we consider such services from the perspective of meeting consumer requirements, it is advisable to highlight several key aspects, in particular, functionality, compliance with user needs, quality level, and implementation and operation costs. The set of these characteristics allows for a comprehensive assessment of the feasibility of using a particular radio communication system for aviation industry.

Functionality corresponds to how fully the system is able to perform the tasks assigned to it and provide the necessary services. It directly affects the usefulness of the service for the consumer and the level of his satisfaction. The wider the range of functions supported by radio communication equipment (for example, voice and navigation information transmission) the higher its practical value. In addition, not only the quantitative but also the qualitative aspect of the implementation of these functions is important, such as their stability, speed, and adaptability to changing operating conditions.

User needs in the field of aviation radio communication form the criteria for selecting and utilizing the appropriate services. They determine how feasible the service is from a practical point of view and whether it meets the expectations of operators and aviation personnel. According to standards, such needs are assessed by indicators of efficiency, level of information security, and safety. Such features are specified through measurable parameters, in particular, system availability, continuity of service provision and integrity of transmitted information.

The reliability of the radio communication system is one of the defining parameters since the stability of the functioning of the entire aviation infrastructure depends on it. It covers such aspects as the ability of the system to remain operational for a given time, the speed of recovery after failures, as well as the possibility of effective maintenance and repair. A high level of reliability is achieved through redundancy, regular diagnostics, and the use of modern technologies of condition monitoring.

The quality of service is a generalized indicator that integrates all of the listed characteristics and reflects the overall beneficial effect of utilizing radio communication service. It is directly related to the degree of satisfaction of user needs and can be considered as a function of one or more technical and operational parameters of the system. However, in real operating conditions, the use of complex mathematical models for its assessment is often limited due to practical implementation complexity. Therefore, it is more appropriate to use a multi-criteria approach, which allows taking into account a set of key indicators, to carry out their comparative analysis and to make informed decisions on improving the efficiency of the functioning of aviation radio communication systems.

Quality of service should be analyzed using a statistical approach since the processes of radio communication systems are probabilistic in nature. Information transmission occurs under the influence of random noises, the level and nature of which can vary in time and space. Connection establishment is also not a deterministic process and occurs at random moments of time depending on the network load, channel status, and other factors. While operating technical means, failures, malfunctions, and degradation of parameters are possible, which are also of a stochastic nature. In this regard, for an adequate description and assessment of QoS indicators, it is necessary to use statistical characteristics (probability distribution function, mathematical expectation, standard deviation, and other indicators) that allow taking into account the uncertainty and variability of processes.

The quality of service parameters can be interpreted as a multidimensional vector, the components of which are individual system parameters, such as delay, throughput, packet loss level, or reliability. This approach allows to consider QoS as a point in the multidimensional space of system states. For practical application, it is necessary to determine the permissible or limiting tolerances for the values of these parameters that meet user requirements or quality standards. The QoS levels in this case are determined by values combinations of all components of the vector, which forms a set of possible system states. Different consumers can put forward their own requirements for the QoS, setting individual threshold values for individual parameters, which necessitates an adaptive approach to QoS management.

Quality of service should be considered in two interrelated dimensions – as a guaranteed and as an actually achieved level. The guaranteed QoS level is formed at the design stage of the radio communication system and is determined by the equipment manufacturer. It is recorded in the technical and operational documentation and reflects the expected characteristics of the system's functioning provided that the specified operating modes are observed. This level is based on a set of tactical and technical parameters, architectural solutions, and envisaged operating conditions, which together determine the potential capabilities of the system to provide the required QoS. The measured QoS level characterizes the real state of the system during its practical use. It is determined by data on key parameters of functioning, their processing, averaging, and subsequent conversion into appropriate quality indicators. Since measurements are carried out over discrete time intervals, the QoS value is dynamic and can change under the influence of load, external interference, technical condition of the equipment, and other factors.

In the overall structure of the quality of service control system (Fig. 1), the interaction between the design and operation stages plays a key role. The equipment manufacturer sets initial QoS parameters and develops recommendations for maintenance, monitoring, and modernization of the system. This allows maintaining the required level of quality throughout the life cycle of the radio communication system, ensuring its adaptation to changing conditions and user requirements.

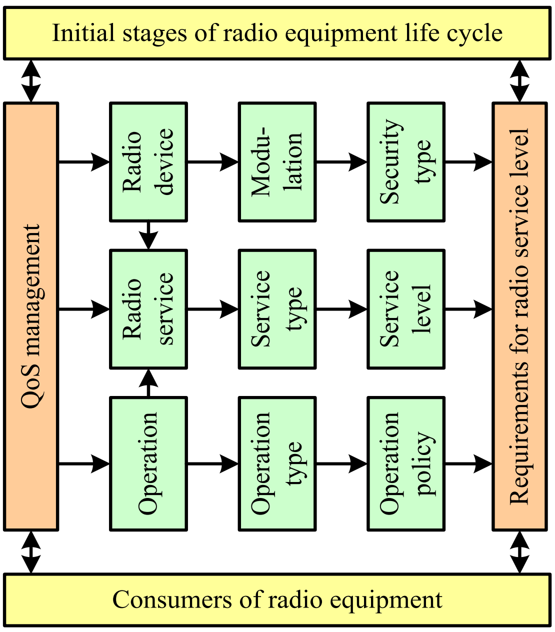

Fig. 1. QoS management system

V. RESULTS

Let's analyze the task of evaluation and simulation of the decision-making procedure concerning to the satisfaction degree for the requirements of the radio services user. It is assumed that the user forms requirements based on three key reliability parameters that reflect the efficiency and stability of the equipment. These parameters include average operating time, average time of repair, and availability coefficient. There are thresholds values for these parameters. The initial dataset include data on failures and repairs, $t_{\mathrm{F}i}$ and $t_{\mathrm{Rep}i}$, respectively.

The average operating time is

$$T_0 = \sum_{i=1}^{N} t_{\mathrm{F}i} \, . \qquad (2)$$

The average time of repair is

$$T_{\mathrm{Rep}} = \sum_{i=1}^{N} t_{\mathrm{Rep}i} \, . \qquad (3)$$

The availability coefficient is

$$K_{\mathrm{A}} = \frac{T_0}{T_0 + T_{\mathrm{Rep}}} \, . \qquad (4)$$

The decision-making process for assessing the QoS of radio equipment can be presented as a three-level model with three possible outcomes. The following states are distinguished:

- full compliance with the requirements, which occurs when none of the three reliability parameters exceeds the established limit values;
- partial compliance, when the threshold level is exceeded for one or two parameters;
- complete non-compliance, which occurs when all three indicators exceed the permissible values.

This approach allows to formalize the assessment process and present it in the form of a mathematical decision-making model

$$Decision = \begin{cases} 1, \text{for full compliance}, \\ 0, \text{ for complete non-compliance}, \\ 0.5, \text{otherwise}. \end{cases} \qquad (5)$$

The simulation process consists of following stages. Firstly, initial dataset was formed. At the second stage, reliability parameters were estimated according to the equations (2), (3), and (4) in sliding window. At the final, decision according to the rule (5) is made.

Figures 2 and 3 shows the initial datasets on failures and repairs. Figure 4 presens the estimates of availability coefficient. The final decisions on the QoS compliance outcomes are shown in Fig. 5.

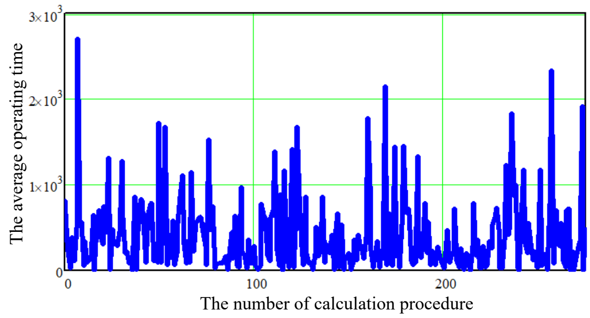

Fig. 2. Times between failures

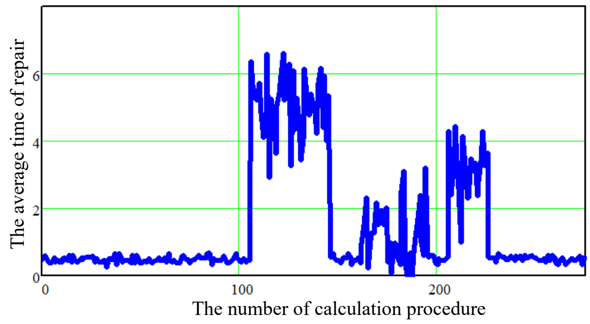

Fig. 3. Times between repairs

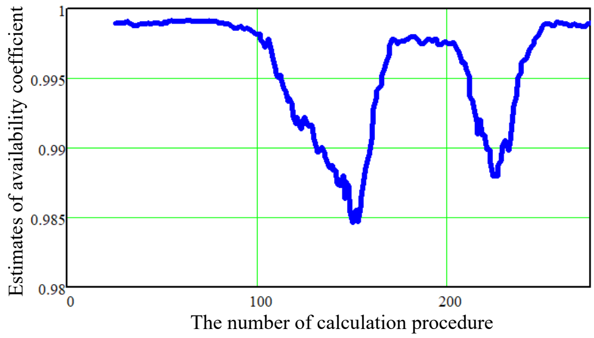

Fig. 4. Estim|ates of availability coefficient

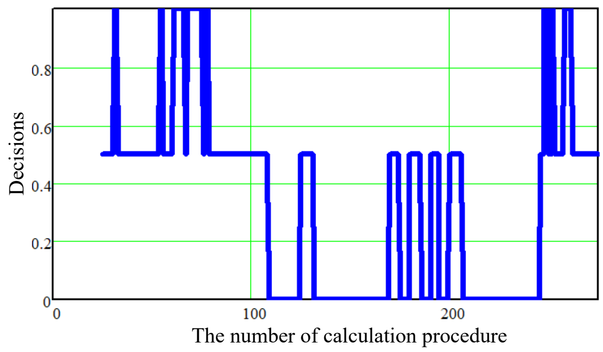

Fig. 5. The final decisions on the QoS compliance

VI. CONCLUSIONS

This article examines key aspects of the functioning of aviation radio systems from the perspective of QoS, reliability, and resource efficiency. It is shown that the QoS is determined by a set of technical, operational, and economic characteristics that reflect the level of satisfaction of user needs. The proposed approaches allow formalizing the decision-making process regarding the state of the radio system in the form of a multi-level model of compliance with user requirements. The obtained results can be used to improve the efficiency of management of aviation radio communication systems and telecommunications infrastructure as a whole.

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Received: March 03, 2026
Accepted: March 20, 2026
Published: April 19, 2026

Tarasiuk Serhii. ORCID 0009-0007-9659-9634. Postgraduate Student.
Department of Telecommunication and Radio Electronic Systems, Faculty of Air Navigation Electronics and Telecommunications, State University "Kyiv Aviation Institute", Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2011).
Research interests: telecommunication networks, radio equipment, data processing.
Publications: 3.
E-mail: 7619224@stud.kai.edu.ua

Konakhovych Georgiy. ORCID 0000-0002-6636-542X. Doctor of Engineering Science. Professor.
Department of Telecommunication and Radio Electronic Systems, Faculty of Air Navigation Electronics and Telecommunications, State University "Kyiv Aviation Institute", Kyiv, Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine, (1968).
Research area: telecommunication networks, radio equipment, information protection, operation.
Publications: more than 200 papers.
E-mail: heorhii.konakhovych@npp.kai.edu.ua

Bondarev Oleksandr. ORCID 0009-0006-5391-8829. Postgraduate Student.
Department of Telecommunication and Radio Electronic Systems, Faculty of Air Navigation Electronics and Telecommunications, State University "Kyiv Aviation Institute", Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2013).

Research interests: telecommunication networks, radio equipment, data processing.
Publications: 10.
E-mail: alexbondarev1990@gmail.com

Zaliskyi Maksym. ORCID 0000-0002-1535-4384. Doctor of Engineering. Professor.
Department of electronics, robotics, and monitoring and IoT technologies, Faculty of Air Navigation, Electronics and Telecommunications, State University "Kyiv Aviation Institute" Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2007).
Research area: operation system, maintenance, statistical data processing, radio engineering equipment.
Publications: 340.
E-mail: maximus2812@ukr.net

С. Ю. Тарасюк, Г. Ф. Конахович, О. С. Бондарев, М. Ю. Заліський. Оцінювання показників якості авіаційних мереж зв'язку

Важливим чинником забезпечення безпеки в авіації є надійна робота систем радіозв'язку. Ці системи забезпечують обмін необхідною інформацією під час польотів і виконання авіаційних операцій, зокрема для керування повітряним рухом, а також процесами зльоту і посадки. Ці системи спрямовані на задоволення потреб авіаційних компаній і підприємств. Засоби радіозв'язку мають певні параметри, які визначають їх ефективність з точки зору призначення, технічного рівня, економічної доцільності, надійності та експлуатаційних характеристик. Окрема група цих параметрів описує якість обслуговування. У цій статті розглядаються характеристики авіаційних систем радіозв'язку з огляду на їх здатність задовольняти потреби користувачів аеронавігаційних послуг. Авторами наведено узагальнений перелік показників якості обслуговування, а також описано підходи до їх обчислення і моделювання. Особливу увагу приділено показникам надійності, аналізу відповідних моделей і специфіці оброблення даних для визначення їх кількісних значень. Отримані результати можуть використовувати фахівці авіаційної галузі під час експлуатації систем радіозв'язку.

Ключові слова: системи радіозв'язку; якість обслуговування; надійність; експлуатація; телекомунікаційна мережа.

Тарасюк Сергій Юрійович. ORCID 0009-0007-9659-9634. Аспірант.
Кафедра телекомунікаційних та радіоелектронних систем, Факультет аеронавігації, електроніки та телекомунікацій, Державний університет «Київський авіаційний інститут», Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2011).
Напрям наукової діяльності: телекомунікаційні мережі, радіообладнання, обробка даних.
Кількість публікацій: 3.
E-mail: 7619224@stud.kai.edu.ua

Конахович Георгій Филимонович. ORCID 0000-0002-6636-542X. Доктор технічних наук. Професор.
Кафедра авіаційних телекомунікаційних та радіоелектронних систем, Факультет аеронавігації, електроніки і телекомунікацій, Державний університет «Київський авіаційний інститут», Київ, Україна.
Освіта: Київський інститут інженерів цивільної авіації, Київ, Україна, (1968).
Напрям наукової діяльності: телекомунікаційні мережі, радіообладнання, захист інформації, експлуатація.
Кількість публікацій: більше 200 наукових робіт.
E-mail: heorhii.konakhovych@npp.kai.edu.ua

Бондарев Олександр Сергійович. ORCID 0009-0006-5391-8829. Аспірант.
Кафедра телекомунікаційних та радіоелектронних систем, Факультет аеронавігації, електроніки та телекомунікацій, Державний університет «Київський авіаційний інститут», Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2013).
Напрям наукової діяльності: телекомунікаційні мережі, радіообладнання, обробка даних.
Кількість публікацій: 10.
E-mail: alexbondarev1990@gmail.com

Заліський Максим Юрійович. ORCID 0000-0002-1535-4384. Доктор технічних наук. Професор.
Кафедра електроніки, робототехніки і технологій моніторингу та інтернету речей, Факультет аеронавігації, електроніки та телекомунікацій, Державний університет «Київський авіаційний інститут», Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2007).
Напрям наукової діяльності: системи експлуатації, обробка статистичних даних, радіоелектронне обладнання.
Кількість публікацій: 340.
E-mail: maximus2812@ukr.net