Electronics and Information Technologies, 2026, 34, 195–206
http://publications.lnu.edu.ua/collections/index.php/electronics/index

UDC: 004.7

METHODS AND MODELS FOR ENSURING QUALITY OF EXPERIENCE IN INFORMATION AND COMMUNICATION SYSTEMS

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Pelekh, P. (2026). Methods and Models for Ensuring Quality of Experience in Information and Communication Systems. *Electronics and Information Technologies*, 34, 195–206. https://doi.org/10.30970/eli.34.12

ABSTRACT

Background. Quality of Experience (QoE) has emerged as a fundamental metric for evaluating the effectiveness of modern information and communication systems, especially in video conferencing environments where real-time interaction is critical. Unlike traditional Quality of Service (QoS) metrics, QoE reflects the subjective perception of users and depends on a combination of technical, behavioral, and contextual factors.

Materials and Methods. The research is based on a comprehensive analysis of contemporary scientific approaches to QoE evaluation in telecommunication systems. A structured set of influencing factors was identified, including technical parameters (network delay, bandwidth, packet loss, noise, and distortions), user-related characteristics (perception, expectations, and interaction behavior), and contextual conditions of service usage. Mathematical modeling methods, including linear regression, neural networks, decision trees, Bayesian approaches, and similarity functions, were considered for predicting QoE. Additionally, the E-model was applied as a standardized approach for evaluating QoS.

Results and Discussion. The experimental results demonstrate that network impairments have a significant negative impact on both QoS and QoE in video conferencing systems. In particular, increased network delays lead to communication interruptions and reduced interactivity, while packet loss results in audio degradation and visual artifacts. The data obtained in this work reveals a strong correlation between objective network parameters and subjective user satisfaction. The conducted modeling confirmed the existence of a nonlinear dependence of QoE on network parameters, particularly delay and packet loss. These results demonstrate the effectiveness of an integrated QoE model in evaluating network services.

Conclusion. The study confirms that network delay and packet loss are among the most influential factors affecting user experience in video conferencing systems. The proposed modeling approach allows for more precise evaluation and forecasting of QoE by incorporating both objective and subjective components. The findings highlight the importance of integrating multiple parameters into unified models for accurate QoE prediction.

Keywords: Quality of Experience, Quality of Service, video conferencing, model, adaptation, communication system.

INTRODUCTION

The QoE (Quality of Experience) model is a tool for assessing the quality of user experience during interaction with technologies and business entities within a specific context, particularly in telecommunication systems. This model takes into account various aspects of the communication ecosystem, such as technical characteristics, business models, user behavior, and usage context.

The QoE model enables the analysis and evaluation of user satisfaction with a particular product or service. It is based on the interaction between the technical parameters of a system and the user's perception of its quality. The main objective of the QoE model is to ensure a high level of user satisfaction and to improve the overall experience of technology use.

This model incorporates various aspects, including audio quality, video quality, data transmission speed, network delay, and other factors. It also considers individual user characteristics, their expectations, and the context in which the technology is used. The QoE model is an important instrument for the design and improvement of telecommunication systems aimed at ensuring a high quality of communication service for end users.

QoE in information and communication technologies plays a key role in ensuring user satisfaction and improving interaction with various services and applications. QoE makes it possible to evaluate Quality of Service (QoS), enhance user interaction, implement traffic management strategies, increase the competitiveness of companies, and improve network monitoring for the rapid detection and resolution of service quality issues before they affect users.

The application of Quality of Experience in information and communication technologies is also important under military conditions. QoE enables the assessment of communication system effectiveness, enhances the productivity and efficiency of military operations, ensures the security and confidentiality of information transmission, and optimizes resource utilization. Such an approach helps to provide reliable communication, fast information exchange, and improved operational efficiency, which are critically important in modern warfare conditions.

MATERIALS AND METHODS

Analysis and Problem Statement

Analyzing the impact of various network parameters on QoE during video conferencing allows the identification of several critical challenges. High network delay leads to interruptions in video transmission and degradation of audio quality, packet loss results in video artifacts and audio dropouts, echo negatively affects speech intelligibility, and network noise introduces distortions that reduce overall sound quality. These factors significantly influence user satisfaction and highlight the need for effective QoE-oriented optimization methods.

In addressing the problem of improving QoE through network parameter optimization, numerous studies have investigated the relationship between technical characteristics and user perception. In particular, the work of Hoßfeld and Pérez [1] proposes a theoretical framework for QoE assessment that integrates both objective measurements and individual user perception. Their approach emphasizes the importance of combining technical monitoring with subjective evaluation to obtain a more accurate representation of user experience.

The study by Seufert et al. [2] focuses on the evaluation and comparison of QoE models using real-world crowdsourced datasets. The authors demonstrate that different

QoE models may produce significantly different results under the same conditions, highlighting the complexity of accurately predicting user experience. Furthermore, Seufert et al. [3] analyze the incompatibility between web and video QoE models, showing that QoE is highly context-dependent and cannot be universally described by a single model.

Schleicher et al. [4] investigate how different stimuli, such as video streaming and web browsing, jointly affect session-level QoE. Their results indicate that QoE cannot be represented as a simple sum of individual components, but rather as a complex interaction of multiple factors. Similarly, Wehner et al. [5] study the impact of content selection strategies on video QoE, particularly in mobile environments, demonstrating that not only network parameters but also content-related factors influence user perception.

In addition, Esper et al. [6] propose QoE-DASH, a tool for evaluating QoE in adaptive streaming systems with edge caching and recommendation mechanisms. Their work highlights the importance of adaptive delivery techniques in maintaining high QoE under varying network conditions. Jelassi and Rubino [7] focus on the development of operative QoE models for IP-based multimedia services, aiming to bridge the gap between theoretical models and practical deployment.

Barakabitze et al. [8] introduce a QoE management architecture for softwarized 5G networks, emphasizing the role of network programmability and dynamic resource allocation in improving user experience. More recent studies, such as d'Arcier et al. [9], explore QoE optimization in distributed XR applications, where real-time performance requirements further increase the sensitivity to network impairments. Similarly, Krogfoss et al. [10] analyze the benefits of 5G and edge computing for QoE in AR/VR environments, demonstrating the importance of low latency and high bandwidth for immersive services.

These studies collectively contribute to the understanding of QoE as a multidimensional concept influenced by technical, contextual, and user-related factors. They highlight the limitations of existing models and the need for more comprehensive approaches that integrate diverse parameters and operating conditions. Based on the analysis of existing scientific works, this study proposes the development of methods and models for optimizing network parameters in order to improve Quality of Experience during video conferencing.

Presentation of the Main Material

The main parameters of the QoE model include various factors that determine the quality of user experience. The key parameters of the QoE model are:

- technical characteristics (data transmission rate, network delay, bandwidth, audio and video quality, noise level, and distortions);
- user behavior (perception of the product or service, level of satisfaction, interaction with the user interface, system response time to user actions);
- usage context (place and time of use, type of device used, specific features of the communication network);
- individual user characteristics (age, gender, experience, etc.);
- interaction model (efficiency and usability of the interface, navigation and information search methods, ease of use of functions and features, level of personalization and individualization of interaction);
- stability and reliability (frequency of errors and failures, recovery time after failures, availability of automatic recovery systems);
- resource consumption (energy usage, computational resource usage, and data volume consumption).

These parameters make it possible to assess Quality of Experience by considering technical, behavioral, and contextual aspects of interaction with technologies and services. By analyzing these parameters, effective strategies can be developed to improve user experience quality and increase user satisfaction with products and services.

Methods for calculating the QoE model may vary depending on the specific usage context and user needs. However, several general approaches can be identified:

User surveys:

- onducting surveys to assess user satisfaction with a product or service;
- using rating scales (e.g., a scale from 1 to 5) to evaluate different aspects of user experience quality.

Objective technical parameters:

- measuring technical characteristics such as data transmission speed, network delay, audio and video quality;
- using specialized software tools to monitor and analyze technical performance indicators.

User behavior analysis:

- tracking user actions within a product or on a website;
- analyzing the time spent performing various tasks and user reactions to different events.

Interaction modeling:

- using mathematical models to predict the impact of various parameters on Quality of Experience;
- applying machine learning methods to analyze large datasets and identify patterns.

Testing with human expert support:

- conducting special tests involving users to evaluate different aspects of experience quality;
- using focus groups and expert assessments to obtain additional feedback.

These methods can be applied individually or in combination to obtain a comprehensive assessment of Quality of Experience in telecommunication systems.

Therefore, this study proposes implementing a method based on mathematical modeling to predict the influence of various parameters on Quality of Experience. This approach involves constructing a mathematical model that reflects the relationship between input parameters (technical, behavioral, contextual) and the output indicator - QoE.

The most common methods for modeling the influence of parameters on QoE include:

- Linear regression. In this method, a linear function is selected that best describes the relationship between input parameters and QoE. For example:

$$QoE = a_1 \cdot n_1 + a_2 \cdot n_2 + \cdots + a_n \cdot n_n + b, \tag{1}$$

  where n_1, n_2,…, n_n are input parameters; a_1, a_2,…, a_n are regression coefficients; and b is the intercept term.
- Neural networks. This method uses artificial neural networks to model complex nonlinear relationships between parameters and QoE. Neural networks can detect complex interactions that cannot be described by linear models.
- Decision trees. In this approach, decision trees are used to identify the most significant parameters influencing QoE. Decision trees can divide input parameters into groups and determine which of them have the greatest impact on Quality of Experience.

- Bayesian methods. Bayesian statistical models are applied to estimate the probability relationships between parameters and QoE. These methods can account for uncertainty and variability in the relationships between parameters.
- Similarity functions. Similarity functions are used to determine the degree of similarity between input parameters and QoE outcomes. They can identify complex heterogeneity in data and determine which parameters have the greatest influence on QoE.

All these methods enable the creation of models capable of effectively predicting Quality of Experience based on various input parameters. Such models contribute to the improvement of products and services in the field of telecommunications, ensuring a high level of service quality for end users.

RESULTS AND DISCUSSION

Based on the QoE model, an experiment was conducted to evaluate the impact of various parameters on user experience quality in telecommunication systems. One possible experimental scenario is described as follows. The objective of the experiment is to determine how network delays affect Quality of Experience during video conferencing. Considering this objective, each stage of the experiment is described in detail below.

Definition of input parameters

Network delay. This parameter is measured in milliseconds and represents the time required to transmit data from the sender to the receiver through the network. Delay measurements are performed using specialized software tools or built-in network monitoring utilities.

Data transmission rate. This parameter is measured as the amount of data that can be transmitted through the network per unit of time (usually in bits per second).

Video and audio quality. Video and audio quality can be measured using various metrics, such as video resolution, audio compression level, noise level, and other indicators.

Preparation of the experimental environment

To conduct the experiment, a testbed with a network featuring controlled delay conditions was created. Software for video conferencing and for monitoring audio and video quality was installed.

Conducting the experiment

Video conferences were carried out under different levels of network delay. By modifying network parameters such as bandwidth and others, different network conditions were reproduced to study their impact on QoE. During the experiment, data on audio and video quality were collected, along with user feedback regarding their experience. The experiment made it possible to determine how network delay affects Quality of Experience and to provide recommendations for improving QoE in video conferencing systems.

Let us examine in more detail each component of the E-model formulas and the formula for evaluating QoE.

1. The E-model for assessing QoS

The E-model formula is expressed as:

$$R = R_0 - I - A - B - C - D, \tag{2}$$

where:
R_0 — initial sound quality, usually measured on a scale from 0 to 100, where 100 represents ideal quality;
I — impact of network delay on sound quality;
A — impact of packet loss on sound quality;
B — impact of echo on sound quality;
C — impact of noise on sound quality;
D — impact of other factors on sound quality.

This model is widely used for assessing speech quality in telecommunication systems and is based on the aggregation of different impairment factors, including noise, delay, packet loss, and equipment-related distortions [11]

Impact of delay (I)

Network delay affects sound quality: the greater the delay, the lower the quality. The delay impact can be calculated as:

$$I = 0{,}024 \cdot t \cdot (95 - R_0), \tag{3}$$

where t is the network delay in milliseconds.

Impact of packet loss (A)

Packet loss also negatively affects sound quality. The impact of packet loss may be calculated as:

$$A = 0.01 \cdot \sum_{i=1}^{n} (95 - R_0) \cdot p_i, \tag{4}$$

where n is the number of lost packets and p_i is the probability of loss of each packet.

Impact of echo (B)

Echo can also degrade sound quality. The impact of echo may be calculated as:

$$B = -0{,}392 \cdot (95 - R_0) \cdot e, \tag{5}$$

where e is the echo level in decibels.

Impact of noise (C)

Noise affects sound quality as well. The impact of noise can be calculated as:

$$C = 0.1 \cdot (95 - R_0) \cdot (1 - 10^{-0.1 \cdot n}), \tag{6}$$

where n is the noise level in decibels.

In formulas (3)-(6), empirical coefficients are introduced that reflect the results of previous studies and represent a generalization of experimentally established dependencies embedded in the classical E-model. In particular, the value 0.024 in formula (3) is a calibration coefficient obtained through statistical analysis of the impact of delay on perceived speech quality and is used to normalize the model's sensitivity to increasing latency. The value 95 in the same formula (as well as in subsequent expressions) corresponds to the reference level of the maximum, conventionally "ideal" speech quality on the R-scale, which is traditionally used in the E-model as a baseline for assessing quality degradation. Similarly, the other coefficients in formulas (4)–(6) (namely 0.01, 0.392, and 0.1) are of empirical origin and were derived through approximation of subjective speech quality test results under different types of network impairments, allowing the mathematical model to be aligned with actual human perception. Thus, all the introduced coefficients ensure that the model corresponds to experimentally validated relationships between network parameters and subjective quality of experience.

Impact of other factors (D)

Other factors, such as compression and jitter, may also influence sound quality.

2. Formula for evaluating QoE based on the E-model

$$QoE = f(QoS, UserFactors), \tag{7}$$

where:
QoS — service quality calculated using the E-model;
$UserFactors$ — individual user characteristics such as gender, age, experience, etc.;
f — a function that accounts for the interaction between service quality and individual user factors.

The function f may take the following form:

$$QoE = f(QoS, UserFactors) = w_1 \cdot QoS + w_2 \cdot UserFactors, \tag{8}$$

where w_1 and w_2 are weighting coefficients reflecting the importance of service quality and individual user factors in QoE assessment.

Let us introduce the variable λ, representing the intensity of packet loss in the network. In this case, the formula for packet loss impact A becomes:

$$A = 0{,}01 \cdot \lambda \cdot \sum_{i=1}^{n} (95 - R_0), \tag{9}$$

where:
λ — parameter reflecting packet loss intensity in the network;
N — number of lost packets;
R_0 — initial sound quality.

Thus, the variable λ accounts for packet loss intensity, enabling a more accurate assessment of its influence on Quality of Service (QoS) and, consequently, on Quality of Experience (QoE). During the experiment, λ can be used to simulate different network conditions with varying packet loss levels. For example, a series of experiments may be conducted with different values of λ to determine the influence of various packet loss intensities on user experience quality.

Figures 1–2 present the results of modeling the dependence of Quality of Experience on network parameters according to formulas (7)–(8), where QoE is defined as an

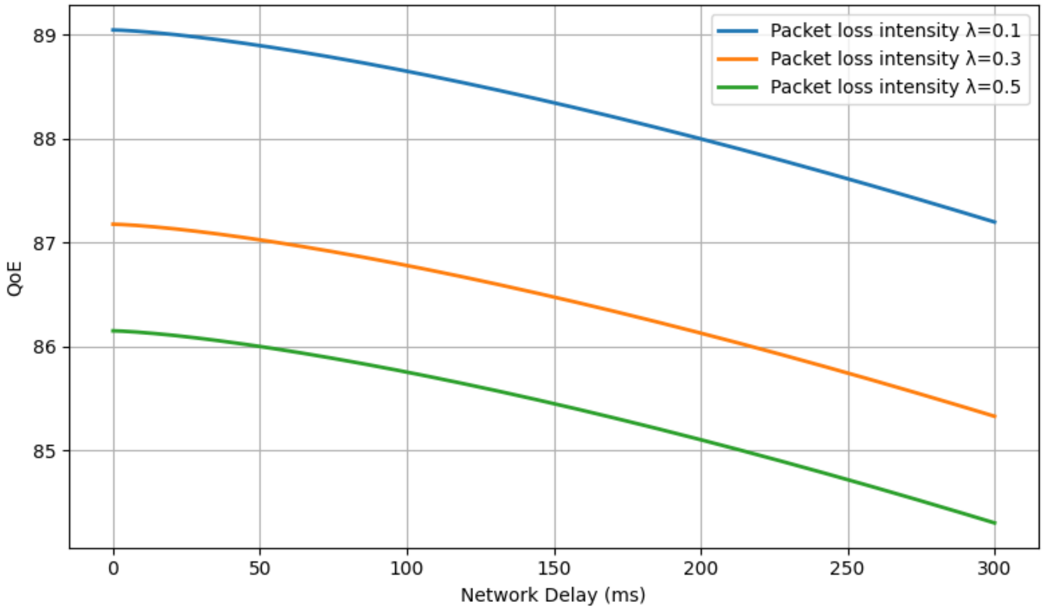

Fig.1. Dependence of QoE on Network Delay

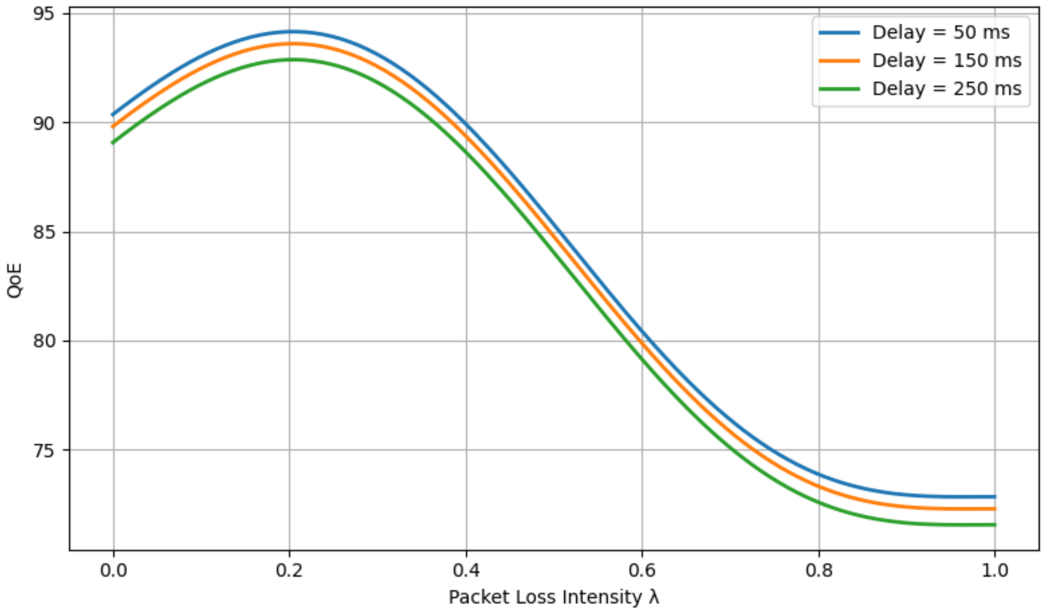

Fig.2. Dependence of QoE on Packet Loss

integrated function of QoS and user-related factors ($UserFactors$). The first graph demonstrates a nonlinear decrease in QoE with increasing network delay under different values of packet loss intensity λ. The obtained results show that even a moderate increase in packet loss leads to a noticeable reduction in QoE at high delay values. The second graph illustrates the dependence of QoE on packet loss intensity under different network delay conditions. It was established that as λ increases, the quality of user experience deteriorates nonlinearly, while the most critical degradation occurs after reaching a certain threshold value of packet loss. In addition, increasing network delay shifts the QoE curves toward lower values, indicating the combined negative influence of delay and packet loss on perceived service quality.

After conducting the experiment to study the impact of network delay on Quality of Experience during video conferencing, the following results were obtained:

Using the E-model, it was determined that network delays negatively affect audio quality during video conferencing. As delay levels increased, audio quality decreased.

The experimental results also showed that packet loss negatively affects audio quality during video conferencing. As the number of lost packets increased, audio quality deteriorated.

Using the QoE evaluation formula, it was determined that Quality of Experience during video conferencing significantly decreases under conditions of high network delay and high packet loss. This confirms the importance of network optimization to ensure a high level of user experience.

Summarizing the results of the study, it is appropriate to compare the obtained dependencies of QoE on network parameters with well-established standards and scientific approaches. According to the ITU-T Recommendation G.107 (E-model), which is a fundamental standard for assessing voice quality in IP networks, the overall quality metric (R-factor) depends on delay, packet loss, and other network impairment factors. This confirms the results obtained in this study regarding the negative impact of latency and packet loss on QoE. Similarly, ITU-T G.1080, which addresses QoE assessment in video conferencing systems, also emphasizes the critical role of network delay and packet loss in shaping the user's subjective perception of quality. Additionally, WebRTC-based experimental studies [12] demonstrate a strong correlation between objective QoS parameters (delay, jitter, packet loss) and subjective QoE ratings provided by users, which is further supported by experimental research using open datasets for real-time video communication. Taken together, these sources confirm the validity of the obtained results and demonstrate that the proposed approach is consistent with international standards and modern QoE modeling methodologies. In future research, it is planned to extend the proposed QoE model by integrating machine learning methods to achieve more accurate nonlinear approximation of the relationships between network parameters and users' subjective experience. It is also intended to conduct experiments in real-world 5G/edge network environments to validate the model and adapt it to different video conferencing scenarios, including mobile and military applications.

CONCLUSION

Based on the results of the experiment, the following conclusions can be drawn. Network delays and packet loss have a significant impact on both Quality of Service and Quality of Experience in telecommunication systems. To ensure a high level of user experience during video conferencing, further research should focus on network optimization aimed at reducing delays and packet loss. In addition, additional studies are required to determine the optimal network parameters for achieving maximum Quality of Experience.

After conducting the experiment using mathematical models to predict the influence of various parameters on Quality of Experience, it was established that incorporating multiple aspects (such as technical characteristics, network parameters, and individual user preferences) provides a more comprehensive understanding of QoE in information and communication technologies.

The experimental results indicate that the use of such models is effective and enables more accurate prediction of service quality in these technologies. This represents an important step toward improving user satisfaction, optimizing network performance, and enhancing the efficiency of information and communication systems, particularly under demanding conditions, such as during military operations. The modeling results demonstrated that QoE strongly depends on network delay and packet loss intensity, while the influence of these parameters is nonlinear in nature. The proposed model makes it possible to consider both technical network characteristics and individual user factors for more accurate service quality assessment.

ACKNOWLEDGMENTS AND FUNDING SOURCES

The author received no financial support for the research, writing, and publication of this article.

CONFLICT OF INTEREST

The author declares that the research was conducted in the absence of any conflict of interest.

AUTHOR CONTRIBUTIONS

The author has read and agreed to the published version of the manuscript.

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МЕТОДИ ТА МОДЕЛІ ЗАБЕЗПЕЧЕННЯ ЯКОСТІ ДОСВІДУ КОРИСТУВАЧА В ІНФОРМАЦІЙНО-КОМУНІКАЦІЙНИХ СИСТЕМАХ

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АНОТАЦІЯ

Вступ. Якість досвіду користувача (ЯДК, Quality of Experience, QoE) стала фундаментальним показником оцінювання ефективності сучасних інформаційно-комунікаційних систем, особливо в середовищі відеоконференцій, де критично важливою є взаємодія в реальному часі. На відміну від традиційних метрик якості обслуговування (ЯО, Quality of Service, QoS), ЯДК відображає суб'єктивне сприйняття користувачів і залежить від поєднання технічних, поведінкових і контекстуальних чинників.

Матеріали та методи. Дослідження ґрунтується на комплексному аналізі сучасних наукових підходів до оцінювання ЯДК в телекомунікаційних системах. Визначено структурований набір чинників впливу, зокрема технічні параметри (мережева затримка, пропускна здатність, втрата пакетів, шум і спотворення), характеристики користувача (сприйняття, очікування та поведінка під час взаємодії), а також контекстні умови використання сервісу. Для моделювання взаємозв'язку між цими параметрами та ЯДК розглянуто низку математичних і аналітичних методів, зокрема лінійну регресію для виявлення лінійних залежностей, штучні нейронні мережі для моделювання нелінійних зв'язків, дерева рішень для аналізу значущості параметрів, байєсівські моделі для ймовірнісного оцінювання та функції подібності для розпізнавання закономірностей.

Результати. Результати експерименту демонструють, що мережеві порушення мають суттєвий негативний вплив як на ЯО, так і на ЯДК у системах відеоконференцій.

Зокрема, збільшення мережевої затримки призводить до переривань у комунікації та зниження інтерактивності, тоді як втрата пакетів спричиняє деградацію звуку та появу візуальних артефактів. Отримані дані виявляють сильну кореляцію між об'єктивними мережевими параметрами та суб'єктивною задоволеністю користувачів. Проведене моделювання підтвердило наявність нелінійної залежності ЯДК від параметрів мережі, зокрема delay та packet loss. Отримані результати демонструють ефективність використання інтегрованої моделі ЯДК для оцінювання якості мережевих сервісів.

Висновки. Дослідження підтверджує, що мережева затримка та втрата пакетів є одними з найважливіших чинників, які впливають на користувацький досвід у системах відеоконференцій. Запропонований підхід до моделювання забезпечує більш точне оцінювання та прогнозування ЯДК за рахунок урахування як об'єктивних, так і суб'єктивних складових. Отримані результати підкреслюють важливість інтеграції множини параметрів у єдині моделі для підвищення точності прогнозування ЯДК.

Ключові слова: якість досвіду користувача, відеоконференції, модель, адаптація.

Received / Одержано	Revised / Доопрацьовано	Accepted / Прийнято	Published / Опубліковано
09 February, 2026	11 May, 2026	15 May, 2026	29 June, 2026