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A COMPARATIVE ANALYSIS OF QoS, GoS, AND QoE METRICS IN NETWORK PERFORMANCE EVALUATION

VAGIF A. GASIMOV, LEYLA R. ZEYNALLI-HUSEYNZADE, GULBICHA A. ZAHIDOVA

Baku Engineering University (Baku, Republic of Azerbaijan)

Abstract. The concepts of QoE (quality of experience), QoS (quality of service), and GoS (goal of service) are commonly discussed in network performance and user satisfaction studies. Although QoE has become a popular topic in research, the boundaries between QoS and QoE are often blurred, making it difficult to clearly define them. This paper examines the differences and relationships between these terms with regard to their practical applications. QoS is a subjective metric that reflects how users perceive a service. It is influenced by personal preferences and various environmental factors. GoS measures the probability of a successful connection or call under certain conditions. The results showed that implementing QoS features such as traffic prioritization can positively affect both GoS and QoE by reducing packet loss and improving service reliability. It is shown how network performance management using QoS tools can improve user experience and overall service reliability, providing a clearer understanding of how these concepts interact in practice.

Keywords: quality of service, grade of service, quality of experience, network performance metrics.

Conflict of interests. The authors declare no conflict of interests.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПОКАЗАТЕЛЕЙ QoS, GoS И QoE ПРИ ОЦЕНКЕ ПРОИЗВОДИТЕЛЬНОСТИ СЕТИ

В. А. КАСУМОВ, Л. Р. ЗЕЙНАЛЛЫ-ГУСЕЙНЗАДЕ, Г. А. ЗАХИДОВА

Бакинский инженерный университет (Хырдалан, Азербайджанская Республика)

Аннотация. Концепции QoE (качество взаимодействия), QoS (качество обслуживания) и GoS (уровень обслуживания) обычно обсуждаются в исследованиях производительности сети и удовлетворенности пользователей. Несмотря на то, что QoE стало популярной темой в исследованиях, границы между QoS и QoE часто размыты, что затрудняет их четкое определение. В статье рассмотрены различия и связи между этими терминами с учетом их практического применения. Качество обслуживания – это субъективный показатель, отражающий то, как пользователи воспринимают услугу. На него влияют личные предпочтения и различные факторы окружающей среды. GoS измеряет вероятность успешного соединения или вызова при определенных условиях. Результаты показали, что внедрение функций QoS, таких как приоритизация трафика, может положительно повлиять как на GoS, так и на QoE, уменьшая потерю пакетов и повышая надежность обслуживания. Показано, как управление производительностью сети с помощью инструментов QoS может повысить удобство работы пользователей и общую надежность услуг, обеспечивая более четкое понимание того, как эти концепции взаимодействуют на практике.

Ключевые слова: качество обслуживания, уровень сервиса, качество взаимодействия, показатели производительности сети.

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Introductıon

In the context of the network media ecosystem, ensuring quality requires a holistic approach that combines technical specifications, user perspectives, and system considerations. However, in most digital multimedia entertainment programs, the overall quality of experience (QoE) accepted by the end user/viewer is considered. QoE encompasses how good the video looks, how well the audio is rendered, how well the combined audio-visual content is accepted, and how well a specific audio-visual service's mutual relationship functions. When referring to video content, quality of service (QoS) is on par with any other service. This includes coverage, continuity of service functionality, provided reliability, device compatibility, and ensuring the quality of signals and features that enable usage. Many agree that digital communication is one of the driving forces for the development of businesses and societies, and it is normal for everyone to expect the best from the telecommunication services they use in their daily digital interactions.

In today's competitive market reality, the customer perspective will definitely demand rejection if a service cannot deliver the highest quality. On the other end of the line, service providers may not be fully informed about the tools that can be used to meet their customers' needs or address their dissatisfaction. To bridge this gap, the concept QoS was introduced as an initiative to enter users' bots and ultimately provide better services and solutions. However, the abundance of overlapping understandings and their confusing abbreviations in telecommunication services does not facilitate the understanding of the importance of QoE. While concepts such as UX (user experience), QoS, GoS (grade of service) or QoE are useful in determining both the quality and quantity parameters of the interaction between the user and the system or service, there has been a recent consensus among experts that the focus should be on QoE [1]. To assess customer satisfaction, QoE has been widely adopted in various industry parameters related to consumer-related aspects. However, since its inception, the Paradigm of QoE has mainly been applied in the telecommunications field, where research tools are the sharpest and measurements are the most accurate.

QoS is a term referring to the technology used to manage information traffic over the network. QoS aims to control and manage network resources to reduce interference such as packet loss and delay. QoS also determines limitations and priorities for different categories of data moving between IP networks, such as bandwidth traffic on the network. It is expected that today's businesses will provide secure and reliable services to end-users with minimal interruptions. In recent years, applications such as audio, video, file sharing, and data streaming have increasingly become part of our daily lives, making QoS more important than ever. The volume of application usage, the increasing number of connected devices to the network, and the significant increase in the importance of social media lead to frequent network congestion. Excessive network loading can cause performance differences. As a result, IT departments are filled with information about video conferences being interrupted, poor audio quality, delays, and even dropped phone calls, which significantly impact daily productivity in the workplace [2]. QoS manages network resources by prioritizing certain types of data communication to determine the transmission needs of multiple data.

Quality of experience and measurement

In the realm of telecommunications, QoE encompasses a broader and more comprehensive range compared to the concept of QoS, which focuses on measuring, improving, and ensuring software and hardware features. To put it simply, QoE refers to the measurement of overall satisfaction with a service from the user's perspective. However, the challenging part comes next. True QoE doesn't aim to measure the objective parameters of system performance (as in QoS). Instead, it aims to encompass the subjective experiences of the service user, including all complexities and factors related to human interactions, such as physical, temporary, social, and even economic aspects. But is it possible to accurately measure someone's subjective feelings about something and derive useful insights from aggregated data? The answer is yes, but with some "buts". Measuring QoE in telecommunications services is quite complex and cannot be successfully achieved without proper tools for data collection and analysis [3]. Therefore, the nature of determining QoE in a specific situation does not solely depend on the quantity or scope of what is measured and converted into metrics. It rather involves understanding which service parameters are the main drivers of user satisfaction and measuring them from a perspective as close to the user's perception as possible. Over the years, awareness of how QoE contributes to increasing user satisfaction and, consequently, user loyalty has been growing among telecommunications operators.

As a result, solutions for monitoring the QoE parameters, especially in telecommunications services, have emerged. However, deriving reliable and consistent results based on these parameters is quite challenging because QoE aims to encompass every factor related to users' perception of service quality, including people, systems, and contextual aspects. Thus, QoE is highly reliant on subjective evaluations. Nevertheless, QoE is determined by using statistical analysis of objective measures through Customer Satisfaction Surveys [4]. QoE evaluations can be subjective or objective. Subjective evaluations are determined by inquiring about quality from human evaluators (though not just based on a single user's opinion). Objective evaluations assess quality based on values obtained through the measurement of assessed systems. Subjective evaluations typically require human evaluators who assess each experience using a five-point scale. The average (or "mean") of the ratings is then considered as the mean opinion score. Evaluations can be conducted in a laboratory or in the field, where they have the following advantages and disadvantages:

• in the laboratory, subjective evaluations can simulate certain conditions of normal usage to some extent, but they never fully reflect normal usage. However, they can be carefully controlled so that evaluators can focus their attention on specific aspects of interest. In particular, evaluated systems can be modified to learn how the evaluators' experience scores change over time. Typically, there are several evaluators (and variations in systems) for people to spend time in the laboratory, due to the costs and efforts involved;

• in the field, subjective judgments can be made under certain conditions of normal usage. For example, services with limited coverage can be tested when the coverage area is available. However, they cannot be performed under all conditions of normal usage. For example, residential multimedia streaming services may not be tested during peak hours at homes. If opinions are gathered through crowdsourcing to assess their own experiences where and when they want, there can be multiple raters, but they may not represent users as a whole.

The most complete possible subjective evaluations of systems do not take into account people's feelings and environments at places and times other than those of the evaluators. Objective evaluations do not require human evaluators, which is why they are often cheaper and faster than subjective evaluations (Fig. 1). They involve measurements of the evaluated systems that can be combined with mathematical models to derive values that often provide mean score estimates. Their accuracy depends on the realism of the models in determining the quality accepted by the average of human evaluators. Typically, models are based on perception theories, empirical studies of influencing factors, and subjective evaluations. They do not consider all factors related to human and context effects on systems. These models are suitable for adaptive streaming and Over-The-Top and managed content providers (ITU-T 2020).

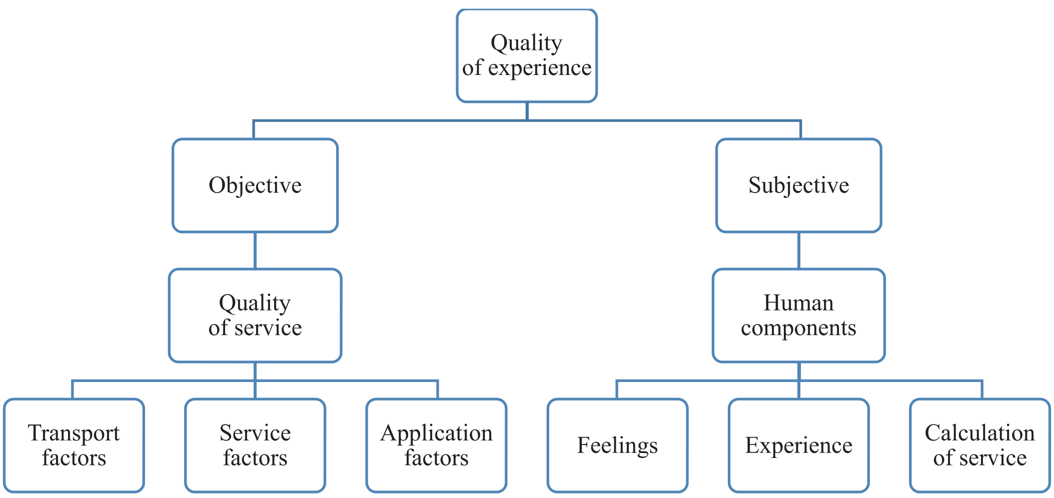

Fig. 1. Types of quality of experience evaluation

Objective evaluations can be conducted in a laboratory, in the field, or in a network environment. They have the following advantages and disadvantages:

• objective evaluations in the laboratory have the same advantages and disadvantages as subjective evaluations in the laboratory;

• objective evaluations in the field can be more reliable than subjective evaluations because they do not require human evaluators. They can be performed at any location and time with appropriate evaluation tools. Installation may require users to have equipment and software installed at their homes or terminals or to have time to travel with equipment or software provided by testers. While achieving this is still challenging, it should be easier than compelling users to conduct regular tests;

• objective evaluations in network environments resemble objective evaluations in the laboratory as they are still not performed under conditions of normal usage. The installation of evaluation tools may be unnecessary, and if equipment and software are already integrated into network nodes or support systems, measurements can cover existing values;

• objective evaluations can be performed without measuring the evaluated systems. Instead, values based on previous knowledge are accepted and combined in a model to provide mean score estimates. This technique is useful for planning networks. Most work on developing QoE standards is based on laboratory evaluations, which can result in products consisting of hardware and software to perform objective evaluations that correspond to subjective mean score evaluations.

Quality of service

Service quality describes and measures the overall performance or output quality of a network service. It can apply to various services such as telephone companies providing voice services, computer networks, or even cloud computing networks. Network performance is measured based on the level of satisfaction experienced by end-users, rather than the guarantees provided by service providers. QoS can be quantified using parameters such as packet loss, bit rate, transmission delay, throughput capacity, availability, and more. However, in the case of packet-switched telecommunication networks like telephone and computer networks, QoS is used to describe traffic management, prioritization, and resource allocation, unlike the actual quality of voice or video streams. Many organizations offer delay-sensitive services like real-time video and voice communication, and they employ QoS to meet the traffic requirements of these types of data. Service class (CoS) can be associated with service quality, but these two concepts are not exactly the same. CoS applies a less detailed approach to traffic management compared to QoS. However, many people use the terms interchangeably, although they represent different concepts. QoS is primarily used by network systems that control data traffic for resource-constrained systems. These services include internet protocol television, online gaming, video conferencing, voice over IP (VoIP) over the internet, video and audio streaming, and demand-based video [5]. Service quality also applies to IoT industries, businesses, and individual end-users. Various QoS tools available possess similar functionalities regardless of the manager. These functionalities include classification, queuing, policing, shaping, weighted random early detection, fragmentation, and compression. QoS can be associated with ensuring the smooth operation of emergency assistance under congested traffic conditions. However, to understand the concept adequately, it is necessary to examine the parameters related to service quality.

The picture below shows the results of the two speed tests, illustrating significant differences in download and upload speeds. Download speed increased from 8.84 to 59.55 Mbps with QoS, highlighting more efficient bandwidth utilization. Upload speed improved from 29.93 to 61.68 Mbps, demonstrating how QoS prioritizes upstream traffic. Latency (Ping) remained stable at 5 ms in both tests, indicating consistent network response times. The figure visually represents the difference in download and upload speeds between the two scenarios:

1) with QoS – both download and upload speeds show a significant increase, ensuring better performance for critical tasks;

2) without QoS – bandwidth allocation is inefficient, leading to lower overall speeds, especially for high-demand activities.

These results clearly show that enabling QoS significantly improves network performance by managing bandwidth more effectively. This ensures that critical services, such as video conferencing or streaming, receive the necessary resources for smooth operation.

Grade of service

It is a measure used to evaluate the performance and availability of a telecommunication network or service. GoS indicates the probability or percentage of successfully completing a call or connection within certain specified criteria. For example, if a GoS of 0.01 is specified, it means that only 1 out of 100 attempted calls may be blocked or fail to connect due to resource limitations. Conversely, a GoS of 0.001 indicates a higher level of service, with only 1 out of 1000 calls being blocked. The specific criteria used to define GoSmay vary depending on the type of service and the industry. In telecommunication networks, GoSis often expressed in terms of call blocking probability, which measures the likelihood of a call being blocked or rejected due to insufficient network resources. A lower call blocking probability indicates a better GoS.

GoS plays a crucial role in network planning, dimensioning, and capacity management. It helps service providers determine the required network resources, such as bandwidth, channels, or connections, to meet the desired level of service [6]. By analyzing the GoS requirements and network performance, providers can make informed decisions on network upgrades, expansions, or optimizations (Fig. 2).

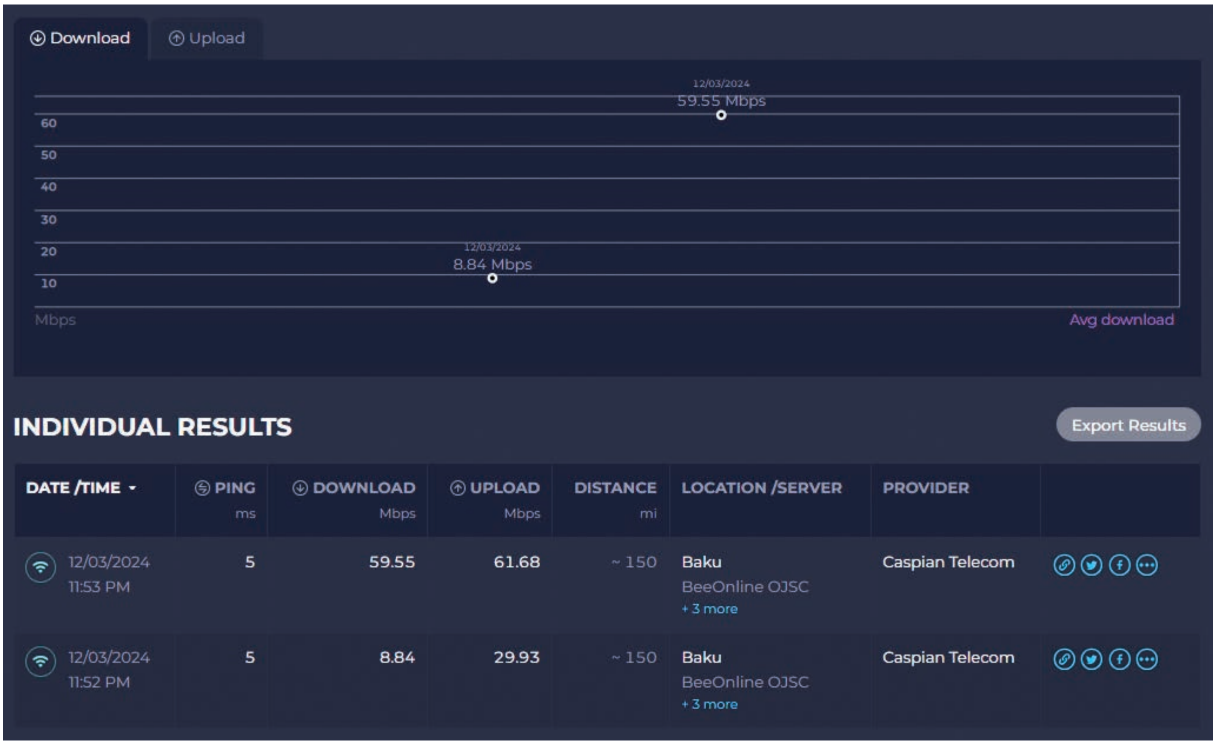

Fig. 2. Comparison of network performance with and without quality of service

Overall, GoS provides a quantitative measure of the service availability and success rates in telecommunication networks. It helps ensure that the network can deliver the desired level of service and meet the expectations of users or customers. GoS metrics are measurements used to assess the performance and quality of a telecommunication system. These metrics help evaluate the level of service provided to users and identify areas for improvement [7]. Here are some common GoS metrics:

• call blocking probability: this metric represents the probability that a call or connection request will be denied or blocked due to insufficient resources in the system. It is typically expressed as a percentage or decimal value, with lower values indicating better service quality;

• call completion rate: this metric measures the percentage of calls or connections that are successfully established and completed without being dropped or disconnected. A higher call completion rate indicates a more reliable and robust system;

• call setup time: this metric measures the time it takes to establish a call or connection from the moment the request is initiated. It includes the time for signaling, routing, and resource allocation. A shorter call setup time indicates faster and more efficient call establishment;

• network congestion: this metric assesses the level of congestion or traffic load on the network. It measures factors such as the number of active calls, data throughput, or utilization of network resources. Monitoring network congestion helps identify periods of high demand and potential bottlenecks;

• QoS parameters: GoS metrics may also include various QoS parameters that measure the quality and performance of the communication service. These parameters can include metrics such as packet loss, delay, jitter, throughput, and availability. They provide insights into the reliability and effectiveness of the network in delivering data or voice services;

• service level agreements (SLAs): SLAs are contractual agreements between service providers and customers that define the expected levels of service quality and performance. GoS metrics can be used to monitor and measure the compliance with SLAs, ensuring that the agreed-upon service levels are being met.

These metrics are typically monitored and analyzed regularly to evaluate the performance of the telecommunication system, identify areas for improvement, and make informed decisions regarding network optimization, capacity planning, and resource allocation.

Assessment of TCP errors with metrics

In this practical analysis, we evaluated the effect of enabling QoS features on a Wi-Fi router to enhance network performance, with a focus on reducing TCP errors and improving both QoE and GoS. The experiment involved capturing network traffic, identifying errors, and assessing the impact of QoS on real-time application performance under typical home network conditions.

The experiment followed these key steps:

• enabling QoS on the router: QoS features were configured to prioritize latency-sensitive traffic (e. g., video streaming, VoIP) while assigning lower priority to background downloads. Rules were set based on application type and specific devices connected to the network;

• traffic monitoring: network traffic was captured using Wireshark on a connected device while various activities, such as streaming, browsing, and downloading, were performed simultaneously;

• error identification: Wireshark filters were applied to isolate TCP errors, focusing on retransmissions, duplicate acknowledgments, and lost packets;

• visualization: TCP error trends were visualized using Wireshark's I/O Graph, which displayed the frequency of errors over time in 1-second intervals.

To conduct the analysis, all QoS settings on the router were enabled, prioritizing high-bandwidth and real-time applications such as video streaming and VoIP traffic. Devices generating significant background traffic were deprioritized to allow optimal allocation of network resources. During the tests, network traffic was captured using Wireshark while activities such as streaming, video calls, and concurrent downloads were performed to simulate real-world conditions. TCP errors, including retransmissions, duplicate acknowledgments, and lost packets, were isolated using specific filters in Wireshark. The captured data was visualized through the I/O graph tool, which displayed error trends over time. Metrics relevant to QoE and GoS, such as error frequency, packet retransmissions, and service stability, were evaluated to understand the impact of QoS (Fig. 3).

Fig. 3. I/O graph from Wireshark, with the data focusing on TCP errors over time

The results demonstrated a significant reduction in the frequency and duration of TCP error spikes after enabling QoS. The I/O graph revealed that error bursts during high traffic demand were shorter and less frequent compared to scenarios without QoS. High-priority applications, such as video calls and streaming services, maintained consistent performance with minimal interruptions. Background downloads experienced minor delays but did not disrupt overall network functionality. With fewer retransmissions and reduced packet loss, video streaming was smoother, and VoIP calls achieved high audio and video quality.

Enabling QoS directly improved the QoE by minimizing disruptions and maintaining consistent service quality during high-demand scenarios. In terms of GoS, QoS ensured reliable service delivery by managing network congestion, reducing packet loss, and prioritizing critical traffic. This demonstrated a clear enhancement in service reliability metrics. The findings highlight the practical value of QoS in improving QoE and GoS in modern networks. By enabling QoS features, network administrators can optimize traffic flow, mitigate the impact of congestion, and ensure high-quality performance for real-time applications. This approach is particularly relevant in environments with bandwidth limitations or competing traffic demands

Conclusion

1. Quality of service (QoS), quality of experience (QoE), and grade of service (GoS) are three related concepts in telecommunications and network management, each focusing on different aspects of service quality:

• QoS:

– refers to measurable parameters that define the performance and reliability of a network or service;

– primarily considers technical factors such as bandwidth, delay, packet loss, jitter, throughput, and availability;

– is defined and implemented by network administrators or service providers to meet specific performance criteria;

– is objective and can be managed using network engineering techniques like traffic shaping, prioritization, and resource allocation;

• QoE:

– focuses on the subjective evaluation of the overall user experience when using a service or application;

– includes factors such as perceived quality of video/audio, responsiveness, ease of use, interactivity, and user satisfaction;

– is influenced by user expectations, personal preferences, and contextual factors;

– is typically assessed through user feedback, surveys, and subjective tests that reflect the user's perception of service quality;

• GoS:

– relates to the level of service provided by a telecommunication network, particularly in terms of the probability of call blocking or dropping;

– is commonly used in voice and real-time communication systems to assess the system's ability to handle traffic load while maintaining service quality;

– relies on the network's capacity to manage expected traffic and ensure desired service levels through proper resource allocation and planning.

2. While these concepts are distinct, they are interconnected and can influence each other. Effective QoS mechanisms directly impact network performance, which, in turn, affects GoS and QoE. A well-designed QoS framework can improve both GoS and QoE by ensuring optimal network performance. Similarly, managing GoS helps reduce call blocking and dropping rates, which can enhance user satisfaction (QoE).

3. The successful implementation of these metrics requires technical expertise, data analysis, and a user-centric approach. Network administrators and engineers must consider the specific requirements of applications and users to optimize QoS, GoS, and QoE. Continuous monitoring and adaptation are essential as technology evolves and user expectations change.

4. This study emphasizes the practical configurations and analysis involved in improving QoS, QoE, and GoS. Implementing QoS features on a Wi-Fi router and analyzing network traffic with tools like

Wireshark demonstrated that QoS mechanisms are crucial for enhancing network performance and user satisfaction.

5. The assessment showed that enabling QoS reduced TCP errors, minimized packet loss, and ensured consistent performance for high-priority applications such as video streaming and VoIP. The I/O graph analysis revealed a decrease in error spikes during high traffic, confirming the effectiveness of traffic prioritization. Additionally, real-time network monitoring and error analysis provided actionable insights into improving QoE and GoS.

6. These findings highlight the importance of proactive network management in environments with diverse traffic demands. By prioritizing critical applications and balancing resource allocation, QoS improves both user experience and network reliability. The results indicate that QoS is not just a theoretical concept but a practical solution for addressing real-world network challenges.

7. Study underscores the importance of applying theoretical concepts in practical scenarios to achieve measurable improvements in network performance. Future research could explore advanced QoS algorithms or evaluate performance under varying network conditions to further refine and optimize service quality.

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Authors' contribution

The authors contributed equally to the writing of the article.

Information about the authors

Gasimov V. A., Dr. Sci. (Tech.), Professor, Dean of the Faculty of Informationa and Computer Technologies, Baku Engineering University (BEU)

Zeynalli-Huseynzade L. R., Lecturer at the Department of Cybersecurity and Computer Engineering, BEU

Zahidova G. A., Lecturer at the Department of Cybersecurity and Computer Engineering, BEU

Address for correspondence

AZ0101, Republic of Azerbaijan,
Khirdalan City, Hasan Aliyev St., 120
Baku Engineering University
Tel.: +994 70 213-99-98
E-mail: vaqasimov@beu.edu.az
Gasimov Vagif Alidjavad ogly