RESEARCH AND ANALYSIS QOS AND QOE INDICATORS IN MULTISERVICE TELECOMMUNICATION NETWORKS

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Abstract

The rapid evolution multiservice telecommunication networks and the increasing demand for multimedia services have heightened the importance of ensuring Quality of Service (QoS) and Quality of Experience (QoE) for user satisfaction. This study explores QoS and QoE metrics in multiservice networks, leveraging insights from the "Network 2030" project, advanced digital technologies like SDN, NFV, 5G, and emerging 6G frameworks. With a focus on modern, end-to-end digital architectures, the paper proposes a mathematical model for analyzing and optimizing performance indicators, considering parameters such as network throughput, reliability, delay, and packet loss. The model aims to support real-time QoE assessments and enhance service quality by identifying performance thresholds across applications, from voice and video to M2M traffic. Metrics are examined through ITU-T recommendations, incorporating probabilistic-temporal characteristics and subjective user perceptions measured by the MOS (Mean Opinion Score) and R-factor ratings. Findings suggest that dynamic QoE monitoring, aligned with the convergence of NGN and FN architectures, offers significant potential to address rising user expectations in content quality and service reliability, guiding future research toward efficient QoS and QoE assessment in multiservice environments.

Keywords: Bandwidth, QoS, based routing, multiservice network, Quality of Experience, network resources.

I. Introduction

The development research outcomes from the "Network 2030" project, conducted by the ITU-T Focus Group FG NET-2030 on exploring the potential and principles building fixed communication networks, alongside the growth in multimedia traffic volume (voice, data, real-time streams, machine to machine (M2M), and video traffic), highlights the importance ensuring timely delivery. One of the key objectives in multiservice telecommunication networks based on end-to-end digital technologies is to guarantee quality of service (QoS) and quality of experience (QoE) for both user and service traffic when providing infocommunication services and applications [1, 2, 3].

It is worth noting that the analysis of real packet transmission paths conducted in [1, 2] shows that both user and service traffic in multiservice telecommunication networks exhibit structural complexity. This complexity reduces the timeliness traffic processing at nodes in multiservice networks based on modern end-to-end digital technologies [4, 5].

Advanced end-to-end digital technologies include SDN (Software Defined Networking), NFV (Network Functions Virtualization), IoT (Internet of Things), LTE (Long Term Evolution), IMS (IP Multimedia Subsystem), AI (Artificial Intelligence), ML, WDM & DWDM (Wavelength Division Multiplexing & Dense Wavelength Division Multiplexing), 5G–NR-U (New Radio-Unlicensed), and 6G [5, 6, 7].

A new model for ensuring service quality and experience has become crucial to achieving the service level expected by today's subscribers. Critical infocommunication services require proactive SLA (Service Level Agreements) monitoring and Diffserv in real time to ensure guaranteed service quality and user experience [6, 7, 8].

Given the above and the shift toward next generation (NGN, Next Generation Network) and future networks (FN, Future Network), improving algorithms and protocols has become especially relevant. These networks provide voice, data, and video transmission services and incorporate the convergence of mobile and fixed public networks [3, 8].

In studies [2, 3, 4], certain tasks related to ensuring QoS and QoE, focusing on optimizing probabilistic and temporal performance metrics in multiservice telecommunication networks, were analyzed. In work [5, 6, 7], methods for routing, traffic clustering, and guaranteed service quality in communication systems were examined, identifying only some performance metrics for transmission efficiency and interference resistance in reception.

An optimization task arises to investigate QoS and QoE metrics by selecting probabilistic and temporal characteristics based on the efficiency criterion of multiservice telecommunication networks built according to the architectural concepts NGN (Next Generation Network), FN (Future Network), and the research outcomes ITU-T FG NET-2030 using the latest end-to-end digital technologies [9, 10, 11].

The goal of this work is to develop a new approach for creating a mathematical model to analyze QoS and QoE characteristics in multiservice telecommunication networks using end-to-end digital technologies.

II. General Problem Statement

In recent years, there has been a shift from heterogeneous public telecommunication networks - each designed to provide a wide range infocommunication services -NGN and FN, known as multiservice telecommunication networks.

It is known [2, 3, 5] that designing multiservice telecommunication networks requires considering that the primary load is generated by infocommunication services and applications such as "Triple Play Service" and "Bandwidth on Demand."

As a result, multimedia load is increasingly occupying a larger share in public communication network traffic, corporate networks, and military networks. The primary development focus of these networks is on creating scalable, mobile, reliable, and secure networks with context-aware delivery of essential, additional, and intelligent services.

It should be noted that to study QoS and QoE for multimedia traffic in NGN and FN networks, the following tasks need to be considered [4, 10, 11]:

- The fundamental concepts of QoS and QoE in multiservice telecommunication networks, taking into account ITU-T recommendations E.800 and G.1000, which define the relationships among operational characteristics - performance, reliability, and probabilistic-temporal characteristics of multiservice networks;
- QoS and QoE characteristics in NGN and FN multiservice networks, based on ITU-T Y.1540;

● Network throughput and reliability indicators in public communication networks, including network availability and the readiness of hardware-software systems;

● Probabilistic-temporal characteristics of the multiservice communication network;

● A broad range of QoS and QoE requirements in multiservice networks;

● The sensitivity various applications to multiservice network characteristics, considering traffic types (voice, e-commerce, video conferencing, email) and their parameters (bandwidth, packet loss, delay, and jitter).

Considering the aforementioned QoS and QoE metrics, a new approach is proposed for developing a mathematical model to analyze and synthesize the quality characteristics multiservice telecommunication networks. This approach selects the target function, which is described by the following objective functions:

$$Q_{KF}[(\lambda_i)] = \mathrm{W}\{Arg \max_i B[Q_S(\lambda_i), Q_E(\lambda_i)]\},\ i = \overline{1,k} \tag{1}$$

under the following constraints

$$G_P(\lambda_i) \geq G_{P.all.}(\lambda_i),\ T_{ptx}(\lambda_i) \geq T_{ptx.all.}(\lambda_i),\ I_S(\lambda_i) \leq I_{S.\mathrm{all.}}(\lambda_i),\ \ i = \overline{1,k} \tag{2}$$

$$C_{.\max}(\lambda_i) \leq C_{\max\ all.}(\lambda_i),\ H_S(\Lambda_i, t) \geq H_{S.all.}(\Lambda_i, t),\quad i = \overline{1,k} \tag{3}$$

where $G_P(\lambda_i) -$ a function that considers the performance criteria of multiservice telecommunication networks, taking into account QoS and QoE metrics, as well as the rate of incoming user and service traffic λ_i, $i = \overline{1,k}$;

$B[Q_S(\lambda_i), Q_E(\lambda_i)] -$ a function that takes into account QoS and QoE characteristics considering the intensity of incoming user and service traffic, λ_i, $i = \overline{1,k}$ respectively; $Q_{KF}(\lambda_i) -$ a function that considers the performance quality criteria multiservice telecommunication networks, taking into account QoS and QoE metrics, as well as the rate of incoming user and service traffic λ_i, $i = \overline{1,k}$;

$T_{ptx}(\lambda_i) -$ a function that considers the probabilistic-temporal characteristics of multiservice telecommunication networks based on packet switching when transmitting the *i*-th packet stream, taking into account the rate incoming user and service traffic λ_i, $i = \overline{1,k}$; $C_{\max}(\lambda_i) -$ criteria that consider the maximum throughput metrics of multiservice communication networks, taking into account the rate of incoming traffic λ_i flow when processing the *i*-th traffic packets;

$H_S(\Lambda_i, t) -$ criteria that consider single and composite reliability metrics of the hardware and software systems of communication networks with a failure rate of Λ_i at time t, respectively $i = \overline{1,k}$;

$I_S(\lambda_1) -$ the information security coefficient of the hardware and software systems communication networks, considering the failure rate λ_i when servicing the *i*-th packet stream at time t: W – operator of the combined transmission of user and service traffic at a network node when evaluating their performance quality as QoS, SLA, and QoE.

$G_{S.all.}(\lambda_i)$, $T_{ptx.all.}(\lambda_i)$, $C_{\max\ all.}(\lambda_i)$, $I_{S.all.}(\lambda_1, t)$ and $H_{S.all.}(\Lambda_i, t) -$ respectively, the allowable values of performance, probabilistic-temporal characteristics, maximum throughput, and resilience of the telecommunication system to information security threats; single and composite reliability metrics of the hardware and software systems of multiservice telecommunication networks, taking into account the intensity λ_i *and* Λ_i when servicing the *i*-th packet stream at time t.

The proposed expressions (1), (2), and (3) define the essence of a new scientific and practical approach through which a mathematical model is built for analyzing and synthesizing QoS and QoE characteristics in multiservice telecommunication networks using modern SDN, NFV, and IMS end-to-end digital technologies that account for comprehensive quality metrics of the communication system's performance.

Additionally, formulas (1), (2), and (3) offer a straightforward analytical expression for the efficiency and interference resistance functions of multiservice network performance based on the next-generation NGN and FN network architecture concepts, projected up to 2030, under the initiative "Network 2030," as reflected in ITU-T recommendations Y.3000 [3, 10, 11, 12].

Thus, a mathematical model is proposed to formalize the problem, aiming to accurately represent the telecommunications processes occurring within the studied segment of the multiservice network when providing infocommunication services and to enable analytical expressions for calculating key QoS and QoE characteristics.

III. Research and Analysis of Quality of Service Metrics in Multiservice Networks

It should be noted that the development of multiservice telecommunication networks is determined by three factors [4, 5, 6]:

- Traffic growth;
- Society's need for new info communication services;
- Advances in end-to-end digital technologies.

However, these factors are not independent; each of them shapes the ideology behind the development of the public telecommunication system. For example, competition among suppliers of terminal, channel, and switching equipment, along with technological advances, has led to a reduction in equipment costs, which, in turn, has stimulated traffic growth, improved QoS and QoE metrics, and the development new core, supplementary, and intelligent services.

One of the most popular data transmission services in recent years is data transmission via the IP protocol. The widespread adoption of the Internet and the services based on it-such as access to Internet resources, Internet service providers, and e-commerce services-has played a key role in this popularization.

However, the rise in the popularity of Internet services does not necessarily mean an increase in the revenue of telecommunications operators providing these services, primarily due to the decline in rates for Internet service provision.

Considering the concept QoS, let us examine the basic concepts in the field of telecommunication service quality. According to the ITU-T recommendation I.112, the entire set of telecommunication services is divided into two types [4, 5, 6, 7]:

- Bearer Service (BS) – traffic transport;
- Teleservice (TS) – communication provision.

The concept of the above-mentioned types of service encompasses [4, 8, 9]:

- Various types of communication – telephony, data transmission, fax, document retrieval;
- Core and supplementary services;
- Information transmission using various switching methods;
- Provision of different transmission mediums – wired, optical (based on WDM and DWDM technologies), and radio communication.

The hierarchy of concepts in the field of telecommunication service quality is shown in Figure 1, as considered in recommendation E.800.

Figure 1 presents the ITU-T model explaining terms related to QoS metrics. As seen in Figure 1, quality of service combines the concepts of effectiveness, security, reliability, and ease of use.

The group of properties such as availability, integrity, and continuity is combined into a single concept – effectiveness, as shown in Figure 1.

Furthermore, from Figure 1, it follows that the performance of a multiservice telecommunication network (NP, Network Performance) characterizes the effectiveness of service for both user and service traffic.

Network characteristics are defined as the ability to ensure communication between users. NP refers to a set parameters that can be calculated and measured according to ITU-T recommendation I.350. Here, the ability to ensure communication is one of the important network resources [5, 10].

Based on the task formulation, the wide range QoS metrics in multiservice networks relates to the resources of network throughput capacity hardware-software systems in the communication system.

The network resources, such as the maximum throughput capacity communication systems $C_{\max}(\lambda_i)$, considering the intensity of the incoming flow λ_i when processing the *i*-th traffic packets, are determined as follows [5]:

$$C_{\max}(\lambda_i) = (\frac{\lambda_i}{N_m}) \cdot E[L_{i.n}] \cdot (\rho_{i.upl.} + \rho_{i.\text{dow.}})^{-1}, \quad i = \overline{1,k} \tag{4}$$

where N_m – the number communication channels established in multiservice communication networks; $E[L_{i.n}]$ – the average length of the transmitted packet when transmitting the *i*-th traffic stream $i = \overline{1,k}$;

$\rho_{i.upl.}$ and $\rho_{i.upl.}$ – respectively, the load coefficients in multiservice communication networks when transmitting messages over the downstream and upstream communication channels.

It should be noted that with the increasing demands for quality of service and quality of experience in multiservice telecommunication networks built on the basis NGN and FN concepts, more and more attention is being paid to routing mechanisms [1, 4].

The reason for this is that the DiffServ functionality, based on priority packet processing at the nodes (routers) of the telecommunication network, can only improve QoS at specific network elements. However, the routing protocol in next generation telecommunication networks must ensure the calculation of one or more paths for packet delivery.

Figure 1 shows the ITU-T model explaining terms in the field QoS and QoE [4, 10]. It should be noted that the terms in the model related to quality of service and quality of experience are defined by ITU-T recommendations E.800, Y.2000, G.628, I.112, and Y.3001 [3, 4, 10, 12].

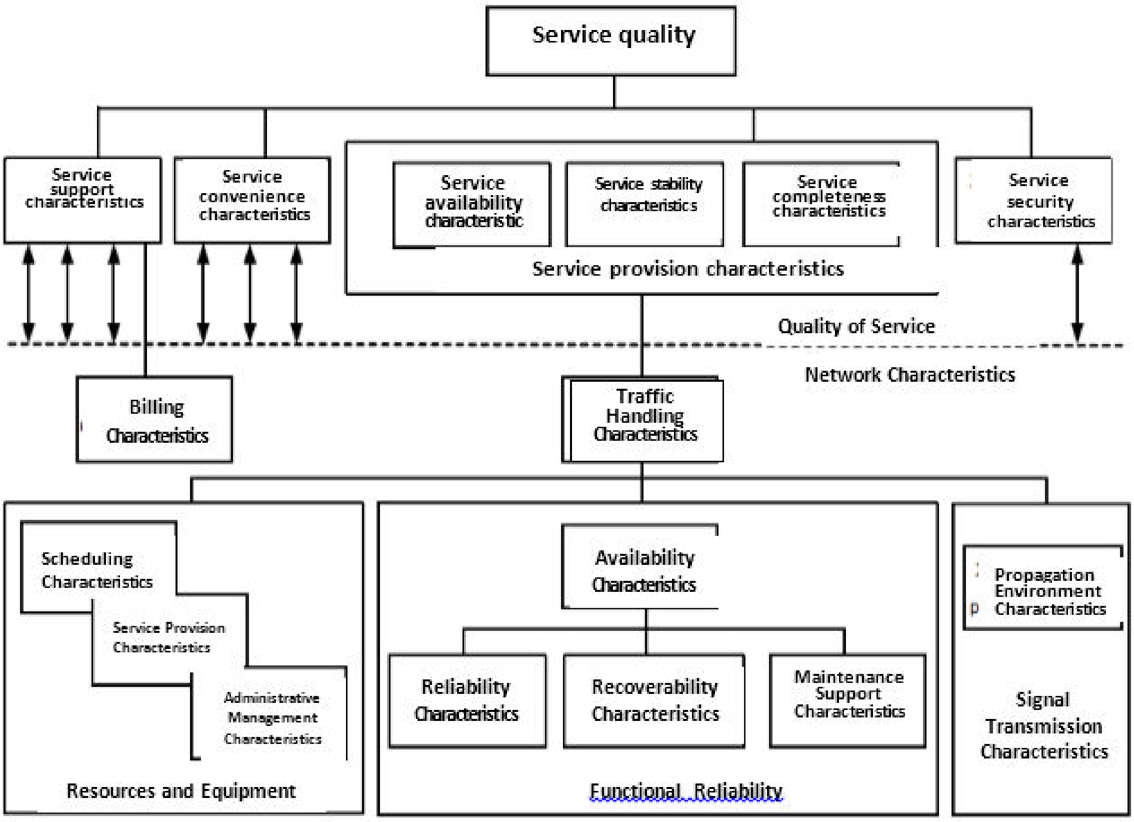

Figure 1: *ITU-T model explaining terms in the field QoS and QoE*

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Table 1 presents the network performance metrics, taking into account QoS classes [4, 11].

Table 1: *Standards for IP network characteristics with distribution by QoS classes*

Network Characteristics	QoS Classes					
	0	1	2	3	4	5
IP Packet Delivery Delay (IPTD)	100 ms	400 ms	100 ms	400 ms	1 s	H
IP Packet Delay Variation (IPDV)	50 ms	50 ms	H	H	H	H
IP Packet Loss Ratio (IPLR)	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	H
IP Packet Error Ratio (IPER)	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	H

The analysis Table 1 shows that the network characteristics include the probabilistic and time characteristics multiservice telecommunication networks, which relate to the performance and interference resistance metrics for receiving user and service traffic.

Furthermore, Table 1 presents the standards for IP network characteristics with distribution by QoS classes. In Table 1 H- indicates that the metrics are not standardized.

IV. Research on Quality of Experience indicators in multiservice networks

Currently, the range infocommunication services provided by operators is significantly expanding, with various applications emerging that enhance users' ability to communicate and exchange information. In addition to the wide range existing applications related to data, voice, and video transmission, the capabilities of heterogeneous networks are opening new horizons for providing new services.

It is worth noting that a prominent example of service penetration into all areas of life is the concept of the Internet of Things, which is changing users' perceptions infocommunication services and telecommunication networks as a whole [1, 7]. It is also a natural process to reconsider the factors affecting the quality of the services provided and, as a result, the transformation of QoS and QoE [2] and the expansion indicators characterizing the level of service quality.

A completely new issue in the field of multiservice networks is the issue of "trust" in the information received from terminal devices, sensors, and detectors. How reliable are the data received, or is it a network failure, data distortion.

This leads to a change in approaches to evaluating QoE for both service and user traffic. The components of perception by humans, which are part of the subjective indicators included in QoE, no longer seem so unattainable, unclear, and useless.

It is known [3, 5, 7] that the most widely used subjective quality assessment methodology is described in ITU-T Recommendation P.800 and is known as the MOS (Mean Opinion Score) method. In multiservice networks, for user and service traffic, expert assessments are determined according to the following five-point scale: 5 – excellent, 4 – good, 3 – acceptable, 2 – poor, 1 – unacceptable.

For speech quality, a MOS score of 3.5 and above corresponds to standard and high telephone quality, 3.0…3.5 is acceptable, and 2.5…3.0 represents synthesized sound. For speech transmission with good quality, it is advisable to aim for a MOS score of at least 3.5. At the same time, R-factor values are directly correlated with MOS scores as follows [4, 10, 11]:

$$R = Ro - ls - ld - le + A \tag{4}$$

where Ro = 93.2 – the initial value of the R-factor; Is – distortions introduced by codecs;

ld – distortions due to total end-to-end delay in the network;

le – distortions introduced by equipment, including packet losses; A – the so-called advantage factor.

From expression (4), it follows that considering the distortions that occur when converting real speech to an electrical signal and back, the theoretical value of the R-factor, without distortions, decreases to a value of 93.2, which corresponds to a MOS score of 4.4.

Table 2 presents the R-factor values and the corresponding MOS scores. From Table 1, it follows that, considering the quality categories and user assessments, the QoS and QoE ratings based on the R-factor and the resulting MOS scores are provided [4,].

Table 2: *R-factor indicators and MOS score values*

R-Factor Value	Quality Category and User Rating	MOS Score Value
90<R<100	Highest	4,34 – 4,50
80<R90	High	4,03 – 4,34
70<R<80	Medium (some users rate quality as unsatisfactory)	3,60 – 4,03

60<R<70	Low (most users rate quality as unsatisfactory)	3,10 – 3,60
50<R<60	Poor (not recommended	2,58 – 3,10

Therefore, the need for a detailed assessment of the quality of service perception, along with the constantly increasing user demands for content parameters, forces the development new approaches for evaluation in multiservice networks. However, dynamic real-time assessment QoE reveals new ways to achieve maximum user satisfaction with services and deepen the emotions they experience.

Thus, timely determination subjective QoE parameters for each user and their correct analysis are promising research directions in the field QoE.

V. Conclusions

1. As a result of the study, a new approach was proposed for creating a mathematical model for analyzing QoS and QoE characteristics in multiservice telecommunication networks and the target function was selected under certain restrictions using end-to-end digital technologies.

2. The proposed mathematical model for analyzing QoS and QoE characteristics takes into account the criteria for the quality of functioning multiservice telecommunication networks and selected as performance parameters, probabilistic-temporal characteristics, throughput, individual and complex indicators of the reliability functioning hardware and software systems, as well as information security of the functioning of multiservice telecommunication networks.

3. The ITU-T model is given, explaining the terms in the field of QoS and QoE, taking into account the ITU-T recommendations, E.800, Y.2000, G.628, I.112 and Y.3001, and the standards for the characteristics IP networks with distribution by quality of service classes and QoE indicators are analyzed, taking into account the R-factor and the MOS assessment value.

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