Abstract

to the thesis research. A subject of this thesis paper:
« Development of a Method for Monitoring Service Quality in a Telecommunication Network»,
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by
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Modern telecommunication systems and data transmission networks generate large volumes of heterogeneous traffic. In such networks, traditional methods of management, monitoring, and data analysis face challenges related to accuracy and the efficient processing of big data in real time. To make an informed decision when selecting an appropriate learning algorithm that meets the specific requirements of an application, it is necessary to understand the advantages and disadvantages of these algorithms in terms of their applicability.

Traffic analysis in data transmission networks serves multiple purposes, such as evaluating the performance and security of network operations and management. Therefore, network traffic analysis is considered an essential element for improving network performance and security.

The application of machine learning methods in the field of traffic analysis demonstrates effective capabilities in addressing network-related problems. The interdisciplinary combination of IP network technologies and intelligent data analysis enables comprehensive evaluation of existing IP networks, identification of bottlenecks, and monitoring of service quality.

Relevance of the Research Topic:

Modern telecommunication networks are experiencing a rapid complication of their architectures, growth of traffic volumes, and diversification of the services provided, which impose new requirements on the reliability and quality of user service (QoS/QoE). The growing number of subscribers, the widespread adoption of cloud technologies, and the emergence of critically important digital services (e-health, e-government, financial services) exacerbate the need for operational and accurate monitoring of the network infrastructure status.

Classical quality control methods — SNMP polling, collection of NetFlow and sFlow metrics, as well as manual analysis of failure logs — prove to be insufficiently sensitive to rapidly evolving or hidden anomalies; they are accompanied by high detection delays for incidents and increase the load on the operator’s equipment. These limitations are especially noticeable under conditions of the implementation of software-defined networks (SDN/NFV) and during the transition to fifth-generation networks (5G), where requirements for SLAs and response time become critically stringent.

Particularly relevant is the development of indirect, minimally invasive monitoring methods that allow diagnosing service quality based on already available statistics of network protocols, without requiring the deployment of expensive sensors or the generation of test traffic. In the context of network scaling and the growing number of potential points of failure, automated predictive tools based on machine learning methods are in high demand, capable not only of detecting incidents but also of forecasting them in advance.

In this context, the task of finding universal, formalized, and interpretable metrics for monitoring services is relevant — metrics that can be implemented in existing OSS/NMS platforms with minimal cost and rapid effect for operations. One such approach is the analysis of PPPoE session statistics, characteristic of broadband access networks, with the identification of new instability indicators and the application of hybrid prediction models.

Thus, research dedicated to the development and implementation of an indirect method of monitoring service quality based on PPPoE statistics and modern data analysis tools meets the current requirements of the industry and contributes to increased resilience, economic efficiency, and technological competitiveness of operator networks.

The presented dissertation work was carried out on the basis of scientific research, methodological, and experimental work, with experiments and modeling performed on the network of one of the telecommunication operators.

The **object** of the study is the processes of monitoring service quality in modern telecommunication networks (SNMP, NetFlow, streaming telemetry, active/passive monitoring). The **subject** of the research is the methods of collecting, analyzing, and predicting service quality metrics based on indirect statistical features of the PPPoE protocol and machine learning methods.

The above conditions form the goal of the dissertation research, which is formulated as follows: **Development of a method for monitoring quality in telecommunication networks.**

In the course of this dissertation research, the following tasks were carried out to achieve the stated objective:

– investigation of service quality monitoring methods and identification of their advantages and limitations;

– determination of a set of initial indirect indicators and assessment of their significance;

– introduction of the instability coefficient K;

– verification of the correctness of the analytical expression for the instability coefficient K using mathematical statistics and simulation modeling;

– comparison of the results of regression and machine learning (ML) models for predicting the instability coefficient K;

– evaluation of the practical significance and economic efficiency of the developed method based on a real operator network.

The scientific novelty of the dissertation lies in the following:

1. **For the first time**, **an approach** to determining a service quality indicator based on indirect statistical features of network protocols (using PPPoE as an

example) is proposed, which makes it possible to diagnose and predict service degradation without direct measurement of QoS parameters and without deploying additional equipment.

2. **For the first time**, a dimensionless **instability coefficient *K***, reflecting the proportion of abnormal connection terminations, has been proposed and analytically substantiated. The use of statistical indicators makes it possible to implement an indirect monitoring approach without generating test traffic and without affecting user services.
3. **A new method** for service quality monitoring based on the instability coefficient *K* has been developed. The method includes statistical analysis algorithms and demonstrates the statistical validity and sensitivity of the proposed indicator to degradation in communication service quality.

Based on the conducted research, the following statements are submitted for defense:

1. **An approach** to determining a service quality indicator based on indirect statistical features of access network protocols without the use of direct QoS measurements.
2. **The instability coefficient *K*** represents an integral indicator of communication service quality and provides a quantitative assessment of connection stability based on indirect statistical data.
3. The proposed **monitoring method** based on the coefficient *K* demonstrates statistical validity and sensitivity.

The approval of the obtained results is confirmed by an implementation act based on the results of the dissertation work from the Republican State Enterprise on the Right of Economic Management "Kazakhstan Interbank Settlement Center" (implementation act dated 15.03.2023) and an informational letter from JSC "Kazakhtelecom". It is noted that the application of the monitoring system made it possible to reduce response times to incidents, provided the ability to track and identify problematic network areas, adjust and improve the quality of the services provided, and conduct tests to optimize the telecommunication network.

The main provisions and results of the research are reflected in scientific publications: six scientific works, including journal articles and conference papers. These include one article published in a domestic scientific journal recommended by the Committee for Quality Assurance in Science and Higher Education (KOQSON); two scientific papers published in the proceedings of international scientific and technical conferences, including papers with oral presentations; as well as four publications indexed in the Scopus database, including three journal articles and one paper published in the proceedings of an international conference.

The Scopus-indexed publications include an Article-type paper published in the *Journal of Theoretical and Applied Information Technology* with a percentile of 17% in the subject area “General Computer Science” at the time of publication; an article in the *Indonesian Journal of Electrical Engineering and Computer Science* with a percentile of 47% in the subject area “Computer Networks and Communications”; an article in the journal *Engineering, Technology & Applied*

Science Research (Q2 quartile) with a percentile of 53% in the subject area "Signal Processing"; as well as a paper published in the proceedings of an international IEEE conference (2020), indexed in the Scopus database.

The **author's personal contribution** to solving the research question is determined by:

- Substantiating, formulating, and developing a method for monitoring service quality in a telecommunication network.
- Computing and introducing an instability coefficient as an effective indicator of service quality.
- Proposing a hypothesis about the effectiveness of the proposed service quality indicator and proving the hypothesis by several methods.
- Conducting and implementing experimental studies on a telecommunications provider's network, as well as carrying out modeling using the specialized software package MATLAB.

The dissertation was prepared by the candidate in accordance with the current requirements for formatting, structure, and content. The work consists of 4 main chapters, regulatory references, designations and definitions, introduction, conclusion, list of references, and appendices.

Chapter One is devoted to the systematization of modern monitoring methods (SNMP, NetFlow, sFlow, model-driven telemetry, active/passive QoS/QoE monitoring, application of ML for anomaly detection). The advantages and limitations of classical and innovative approaches are highlighted, and the requirements for monitoring in SDN/NFV and cloud networks are analyzed.

In the second chapter of the dissertation, the selection of the PPPoE protocol as a source of statistical data for service quality monitoring is substantiated. Indirect indicators of user connection operation formed during the establishment and termination of PPPoE sessions (PADI, PADO, PADR, PADS, PADT) are examined. It is shown that the change in the number of abnormal session terminations (ΔPADT) is an informative indicator of connection instability and can be used to detect signs of network service degradation.

A dimensionless instability coefficient K, characterizing the relative proportion of abnormal PPPoE session terminations within a given time interval, is introduced and analytically justified. It is shown that the proposed indicator makes it possible to quantitatively evaluate the stability of user connections and to compare the network state under different load levels. The architecture of statistical data collection and preprocessing is described, and a simulation model developed in MATLAB is presented, which was used to verify the proposed formula of the instability coefficient.

The third chapter is dedicated to building and comparing models for predicting K: from linear regressions to tree ensembles (Random Forest, XGBoost), neural networks (MLP, LSTM), and symbolic regression. For each model, accuracy metrics are presented, engineering use case scenarios are provided, and recommendations for industrial implementation are given. The importance of the

interpretability of formulas and the advantages of ML approaches in predictive analytics is emphasized.

The fourth chapter describes the experience of implementing the method in the backbone-access segment of a large operator. The monitoring results over 8 weeks are presented, cases of detecting and eliminating real failures are provided (for example, on VLAN 303), and a detailed analysis is performed on the dynamics of the metrics, the impact on MTTR, economic efficiency (CAPEX, OPEX, ROI), and the effect on customer service.

The conclusion summarizes the obtained research results and the main findings of the dissertation.

The appendices contain the following key data from the research results:

1. Tables of initial (source) data.
2. Listing of codes for the simulation model.
3. Listing of codes for machine learning.
4. Listing of the developed software.
5. Copy of the implementation act of the main research results.
6. Copy the informational letter.