

Wojciech Zamojski
Jacek Mazurkiewicz
Jarosław Sugier
Tomasz Walkowiak
Janusz Kacprzyk *Editors*

Advances in Dependability Engineering of Complex Systems

Proceedings of the Twelfth
International Conference on
Dependability and Complex Systems
DepCoS-RELCOMEX, July 2–6, 2017,
Brunów, Poland

Advances in Intelligent Systems and Computing

Volume 582

Series editor

Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

About this Series

The series “Advances in Intelligent Systems and Computing” contains publications on theory, applications, and design methods of Intelligent Systems and Intelligent Computing. Virtually all disciplines such as engineering, natural sciences, computer and information science, ICT, economics, business, e-commerce, environment, healthcare, life science are covered. The list of topics spans all the areas of modern intelligent systems and computing.

The publications within “Advances in Intelligent Systems and Computing” are primarily textbooks and proceedings of important conferences, symposia and congresses. They cover significant recent developments in the field, both of a foundational and applicable character. An important characteristic feature of the series is the short publication time and world-wide distribution. This permits a rapid and broad dissemination of research results.

Advisory Board

Chairman

Nikhil R. Pal, Indian Statistical Institute, Kolkata, India
e-mail: nikhil@isical.ac.in

Members

Rafael Bello Perez, Universidad Central “Marta Abreu” de Las Villas, Santa Clara, Cuba
e-mail: rbellop@uclv.edu.cu

Emilio S. Corchado, University of Salamanca, Salamanca, Spain
e-mail: escorchado@usal.es

Hani Hagrass, University of Essex, Colchester, UK
e-mail: hani@essex.ac.uk

László T. Kóczy, Széchenyi István University, Győr, Hungary
e-mail: koczy@sze.hu

Vladik Kreinovich, University of Texas at El Paso, El Paso, USA
e-mail: vladik@utep.edu

Chin-Teng Lin, National Chiao Tung University, Hsinchu, Taiwan
e-mail: ctlin@mail.nctu.edu.tw

Jie Lu, University of Technology, Sydney, Australia
e-mail: Jie.Lu@uts.edu.au

Patricia Melin, Tijuana Institute of Technology, Tijuana, Mexico
e-mail: epmelin@hafsamx.org

Nadia Nedjah, State University of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: nadia@eng.uerj.br

Ngoc Thanh Nguyen, Wroclaw University of Technology, Wroclaw, Poland
e-mail: Ngoc-Thanh.Nguyen@pwr.edu.pl

Jun Wang, The Chinese University of Hong Kong, Shatin, Hong Kong
e-mail: jwang@mae.cuhk.edu.hk

More information about this series at <http://www.springer.com/series/11156>

Wojciech Zamojski · Jacek Mazurkiewicz
Jarosław Sugier · Tomasz Walkowiak
Janusz Kacprzyk
Editors

Advances in Dependability Engineering of Complex Systems

Proceedings of the Twelfth International
Conference on Dependability and Complex
Systems DepCoS-RELCOMEX,
July 2–6, 2017, Brunów, Poland

Editors

Wojciech Zamojski
Department of Computer Engineering
Wrocław University of Science
and Technology
Wrocław
Poland

Tomasz Walkowiak
Department of Computer Engineering
Wrocław University of Science
and Technology
Wrocław
Poland

Jacek Mazurkiewicz
Department of Computer Engineering
Wrocław University of Science
and Technology
Wrocław
Poland

Janusz Kacprzyk
Systems Research Institute
Polish Academy of Sciences
Warsaw
Poland

Jarosław Sugier
Department of Computer Engineering
Wrocław University of Science
and Technology
Wrocław
Poland

ISSN 2194-5357

ISSN 2194-5365 (electronic)

Advances in Intelligent Systems and Computing

ISBN 978-3-319-59414-9

ISBN 978-3-319-59415-6 (eBook)

DOI 10.1007/978-3-319-59415-6

Library of Congress Control Number: 2017940846

© Springer International Publishing AG 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature

The registered company is Springer International Publishing AG

The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This volume presents proceedings of the Twelfth International Conference on Dependability and Complex Systems DepCoS-RELCOMEX which took place in the Brunów Palace in Poland from 2nd to 6th July 2017.

The volume appears in the series “Advances in Intelligent Systems and Computing” (AISC) published by Springer Nature, one of the largest and most prestigious scientific publishers, in the series which is one of the fastest growing book series in their programme. The AISC is meant to include various high-quality and timely publications, primarily conference proceedings of relevant conference, congresses and symposia but also monographs, on the theory, applications and implementations of broadly perceived modern intelligent systems and intelligent computing, in their modern understanding, i.e. including tools and techniques of artificial intelligence (AI), computational intelligence (CI)—which includes neural networks, fuzzy systems, evolutionary computing, as well as hybrid approaches that synergistically combine these areas—but also topics such as multiagent systems, social intelligence, ambient intelligence, Web intelligence, computational neuroscience, artificial life, virtual worlds and societies, cognitive science and systems, perception and vision, DNA and immune-based systems, self-organizing and adaptive systems, e-learning and teaching, human-centred and human-centric computing, autonomous robotics, knowledge-based paradigms, learning paradigms, machine ethics, intelligent data analysis, various issues related to “big data”, security and trust management, to just mention a few. These areas are at the forefront of science and technology, and have been found useful and powerful in a wide variety of disciplines such as engineering, natural sciences, computer, computation and information sciences, ICT, economics, business, e-commerce, environment, health care, life science and social sciences. The AISC book series is submitted for indexing in ISI Conference Proceedings Citation Index (now run by Clarivate), EI Compendex, DBLP, SCOPUS, Google Scholar and SpringerLink, and many other indexing services around the world.

DepCoS-RELCOMEX is an annual conference series organized since 2006 at the Faculty of Electronics, Wrocław University of Science and Technology, formerly by Institute of Computer Engineering, Control and Robotics (CECR) and

now by Department of Computer Engineering. Its idea came from the heritage of the other two cycles of events: RELCOMEX (1977–89) and Microcomputer School (1985–95) which were organized by the Institute of Engineering Cybernetics (the previous name of CECR) under the leadership of Prof. Wojciech Zamojski, still the DepCoS chairman, so this year we can celebrate the 40th anniversary of its origins. In this volume of “Advances in Intelligent Systems and Computing”, we would like to present results of studies on selected problems of complex systems and their dependability. Effects of the previous DepCoS events were published (in chronological order) by IEEE Computer Society (2006–09), by Wrocław University of Technology Publishing House (2010–12) and presently by Springer in “Advances in Intelligent Systems and Computing” volumes no. 97 (2011), 170 (2012), 224 (2013), 286 (2014), 365 (2015) and 479 (2016).

Dependability is the contemporary answer to new challenges in reliability evaluation of complex systems. Dependability approach in theory and engineering of complex systems (not only computer systems and networks) is based on multidisciplinary attitude to system theory, technology and maintenance of the systems working in real (and very often unfriendly) environments. Dependability concentrates on efficient realization of tasks, services and jobs by a system considered as a unity of technical, information and human assets, in contrast to “classical” reliability which is more restrained to analysis of technical resources (components and structures built from them). Such a transformation has shaped natural evolution in topical range of subsequent DepCoS conferences which can be seen over the recent years. This edition additionally hosted the 7th CrISS-DESSERT Workshop devoted particularly to the challenges and solutions in analysis and assurance of critical infrastructure and computer (software and programmable logic-based) system safety and cybersecurity.

The Programme Committee of the 12th International DepCoS-RELCOMEX Conference, its organizers and the editors of these proceedings would like to gratefully acknowledge participation of all reviewers who helped to refine contents of this volume and evaluated conference submissions. Our thanks go to, in alphabetic order, Andrzej Białas, Ilona Bluemke, Eugene Brezhniev, Dariusz Caban, Frank Coolen, Manuel Gil Perez, Zbigniew Huzar, Igor Kabashkin, Vyacheslav Kharchenko, Leszek Kotulski, Alexey Lastovetsky, Jan Magott, István Majzik, Jacek Mazurkiewicz, Marek Młyńczak, Yiannis Papadopoulos, Oksana Pomorova, Krzysztof Sacha, Rafał Scherer, Mirosław Siergiejczyk, Janusz Sosnowski, Jarosław Sugier, Victor Toporkov, Tomasz Walkowiak, Irina Yatskiv, Wojciech Zamojski and Włodzimierz Zuberek.

Thanking all the authors who have chosen DepCoS as the publication platform for their research, we would like to express our hope that their papers will help in further developments in design and analysis of engineering aspects of complex systems, being a valuable source material for scientists, researchers, practitioners and students who work in these areas.

The Editors

Twelfth International Conference on Dependability and Complex Systems DepCoS-RELCOMEX

organized by
Department of Computer Engineering,
Wrocław University of Science and Technology
Brunów Palace, Poland, 2–6 July 2017

Programme Committee

| | |
|---------------------------------|--|
| Wojciech Zamojski (Chairman) | Wrocław University of Science and Technology, Poland |
| Ali Al-Dahoud | Al-Zaytoonah University, Amman, Jordan |
| George Anders | University of Toronto, Canada |
| Włodzimierz M. Barański | Wrocław University of Science and Technology, Poland |
| Andrzej Białas | Institute of Innovative Technologies EMAG, Katowice, Poland |
| Ilona Bluemke | Warsaw University of Technology, Poland |
| Eugene Brezhnev | National Aerospace University “KhAI”, Kharkiv, Ukraine |
| Dariusz Caban | Wrocław University of Science and Technology, Poland |
| Krzysztof Cios | Virginia Commonwealth University, Richmond, USA |
| Frank Coolen | Durham University, UK |
| Mieczysław Drabowski | Cracow University of Technology, Poland |
| Francesco Flammini | University of Naples “Federico II”, Napoli, Italy |
| Manuel Gill Perez | University of Murcia, Spain |

| | |
|--------------------------|--|
| Zbigniew Huzar | Wrocław University of Science and Technology, Poland |
| Igor Kabashkin | Transport and Telecommunication Institute, Riga, Latvia |
| Janusz Kacprzyk | Polish Academy of Sciences, Warsaw, Poland |
| Vyacheslav S. Kharchenko | National Aerospace University “KhAI”, Kharkiv, Ukraine |
| Mieczysław M. Kokar | Northeastern University, Boston, USA |
| Krzysztof Kołowrocki | Gdynia Maritime University, Poland |
| Leszek Kotulski | AGH University of Science and Technology, Krakow, Poland |
| Henryk Krawczyk | Gdansk University of Technology, Poland |
| Alexey Lastovetsky | University College Dublin, Ireland |
| Marek Litwin | ITS Polska, Warsaw, Poland |
| Jan Magott | Wrocław University of Science and Technology, Poland |
| Istvan Majzik | Budapest University of Technology and Economics, Hungary |
| Jacek Mazurkiewicz | Wrocław University of Science and Technology, Poland |
| Marek Młyńczak | Wrocław University of Science and Technology, Poland |
| Yiannis Papadopoulos | Hull University, UK |
| Oksana Pomorova | Khmeltsky National University, Ukraine |
| Ewaryst Rafajłowicz | Wrocław University of Science and Technology, Poland |
| Krzysztof Sacha | Warsaw University of Technology, Poland |
| Rafał Scherer | Częstochowa University of Technology, Poland |
| Mirosław Siergiejczyk | Warsaw University of Technology, Poland |
| Czesław Smutnicki | Wrocław University of Science and Technology, Poland |
| Janusz Sosnowski | Warsaw University of Technology, Poland |
| Jarosław Sugier | Wrocław University of Science and Technology, Poland |
| Victor Toporkov | Moscow Power Engineering Institute (Technical University), Russia |
| Tomasz Walkowiak | Wrocław University of Science and Technology, Poland |
| Max Walter | Siemens, Germany |
| Bernd E. Wolfinger | University of Hamburg, Germany |
| Leonid G. Voskressensky | Peoples' Friendship University, Moscow, Russia |

| | |
|---------------------|--|
| Min Xie | City University of Hong Kong, Hong Kong SAR, China |
| Irina Yatskiv | Transport and Telecommunication Institute, Riga, Latvia |
| Włodzimierz Zuberek | Memorial University, St.John's, Canada |

Organizing Committee

Honorary Chairman

Wojciech Zamojski

Members

Włodzimierz M. Barański
Jacek Mazurkiewicz
Jarosław Sugier
Tomasz Walkowiak

Seventh CrISS-DESSERT Workshop

Critical Infrastructure Security and Safety (CrISS) -
Dependable Systems, Services & Technologies (DESSERT)

The CrISS-DESSERT Workshop evolved from the conference *Dependable Systems, Services & Technologies* DESSERT 2006–2016 (www.dessertcon.com). The 6th CrISS-DESSERT took place in Chernivtsi, Ukraine, 21–22 May 2016. In 2017, the 7th CrISS-DESSERT Workshop was held in the frameworks of the 12th Conference on Dependability and Complex Systems DepCoS-RELCOMEX.

The mission of the Workshop was to discuss challenges and solutions related to analysis and assurance of critical infrastructure and computer (software and programmable logic-based) system safety and cybersecurity. In particular, its focus was chosen in order to address:

- interplay and interdependencies of system of systems (telecommunication, smart grid, intelligent transportation system, etc.) and the current problems in providing its safety, security, reliability, quality of services, etc.;
- roles played by IT (SW, HW, FPGA)-based systems as the mandatory part of each infrastructure, thus turning distinct infrastructures into a complex cyber-physical system (system of systems) with emergent and cooperative behaviour, uncertainties, etc.;
- resource-effective IT-based approaches to safe and sustainable development.

The CrISS Workshop examined modelling, development, integration, verification, diagnostics and maintenance of computer and communications systems and infrastructures for safety-, mission- and business-critical applications.

Main Topics

The main topics on the workshop agenda included the following:

- Formal methods for critical IT infrastructures and systems development and verification
- Vulnerability analysis and intrusion-tolerant systems
- Evolving infrastructures and self-systems

- Dependability and resilience of Web-, cloud- and IoT-based IT infrastructures
- Safety of human-machine interfaces and systems including cooperative HMI&S
- Functional/system safety perspective of intelligent transport systems (ITS)
- Information & data modelling in ITS context
- IT infrastructures for pre- and post-accident monitoring of critical objects
- Safety- and assurance-case methodologies, techniques and tools
- Smart grid safety, reliability and security
- Power saving in IT infrastructures, data centres and computing clusters

Workshop Panel Discussion

Infrastructure and industrial systems safety and security: challenges, monitoring and assurance case-based solutions.

Workshop Chair

| | |
|-----------------------|--|
| Vyacheslav Kharchenko | National Aerospace University KhAI, Centre for Safety Infrastructure Oriented Research and Analysis, Ukraine |
|-----------------------|--|

Co-chairs

| | |
|---------------|--|
| Todor Tagarev | Institute of Information and Communication Technologies, Bulgaria (TBC) |
| Nikos Bardis | Hellenic Military Academy, Greece |

Industry Partner

RPC Radiy, Ukraine

Contents

| | |
|--|----|
| Detection of Network Attacks Using Hybrid ARIMA-GARCH Model | 1 |
| Tomasz Andrysiak, Łukasz Saganowski, Mirosław Maszewski, and Adam Marchewka | |
| Towards Mixed-Mode Risk Management – A Concept | 13 |
| Andrzej Bialas and Barbara Flisiuk | |
| Software Support of the Common Criteria Vulnerability Assessment | 26 |
| Andrzej Bialas | |
| On the Performance of Some C# Constructions | 39 |
| Ilona Bluemke, Piotr Gawkowski, Waldemar Grabski, and Konrad Grochowski | |
| Deep Stacking Convex Neuro-Fuzzy System and Its On-line Learning | 49 |
| Yevgeniy Bodyanskiy, Olena Vynokurova, Iryna Pliss, Dmytro Peleshko, and Yuriy Rashkevych | |
| Fault Tolerant ASIC/ULA-Based Computing Systems Testing via FPGA Prototyping with Fault Injection | 60 |
| Oleg Brekhov and Alexander Klimenko | |
| Critical Energy Infrastructure Safety Assurance Strategies Considering Emergent Interaction Risk | 67 |
| Eugene Brezhnev, Vyacheslav Kharchenko, Viacheslav Manulik, and Konstantin Leontiev | |
| Modelling an Optimal Capital Structure of the Telecommunication Company | 79 |
| Alexandr Y. Bystryakov, Tatiana K. Blokhina, Elena V. Savenkova, Oksana A. Karpenko, and Elena V. Ponomarenko | |

| | |
|--|------------|
| Specification of Constraints in a System-of-Systems Configuration | 89 |
| Dariusz Caban and Tomasz Walkowiak | |
| A Methodological Framework for Model-Based Self-management of Services and Components in Dependable Cyber-Physical Systems | 97 |
| DeJiu Chen and Zhonghai Lu | |
| Maintenance of Wind Turbine Scheduling Based on Output Power Data and Wind Forecast. | 106 |
| Guglielmo D'Amico, Filippo Petroni, and Robert Adam Sobolewski | |
| Deadlock Detection in Distributed Systems Using the IMDS Formalism and Petri Nets. | 118 |
| Wiktor B. Daszczuk and Wlodek M. Zuberek | |
| Scheduling Tasks in Embedded Systems Based on NoC Architecture Using Simulated Annealing | 131 |
| Dariusz Dorota | |
| Adaptation of Ant Colony Algorithm for CAD of Complex Systems with Higher Degree of Dependability. | 141 |
| Mieczyslaw Drabowski | |
| Context-Aware Anomaly Detection in Embedded Systems | 151 |
| Fateme Ehsani-Besheli and Hamid R. Zarandi | |
| Comparative Analysis of Calculations in Cryptographic Protocols Using a Combination of Different Bases of Finite Fields | 166 |
| Sergey Gashkov and Alexander Frolov | |
| Dynamic Redundancy in Communication Network of Air Traffic Management System. | 178 |
| Igor Kabashkin | |
| Availability Models and Maintenance Strategies for Smart Building Automation Systems Considering Attacks on Component Vulnerabilities | 186 |
| Vyacheslav Kharchenko, Yuriy Ponochovnyi, Al-Sudani Mustafa Qahtan Abdulmunem, and Anton Andrashov | |
| Concept of Multi-criteria Evaluation of the Airport Security Control Process. | 196 |
| Artur Kierzkowski and Tomasz Kisiel | |
| Extending Continuous Integration with Post-mortem Debug Automation of Unhandled Exceptions Occurred in Kernel or User Mode Applications | 205 |
| Henryk Krawczyk and Dawid Zima | |

| | |
|--|------------|
| The Methodology of Studying of Active Traffic Management Module Self-oscillation Regime | 215 |
| Dmitry S. Kulyabov, Anna V. Korolkova, Tatyana R. Velieva, Ekaterina G. Eferina, and Leonid A. Sevastianov | |
| Effectiveness Examination of a Multi-channel CSMA/CA Detector. | 225 |
| Dariusz Laskowski, Marcin Pólkowski, Piotr Łubkowski, and Leszek Nowosielski | |
| IaaS vs. Traditional Hosting for Web Applications - Cost Effectiveness Analysis for a Local Market | 233 |
| Paweł Lorenc and Marek Woda | |
| High Quality Stabilization of an Inverted Pendulum Using the Controller Based on Trigonometric Function | 244 |
| Michał Lower | |
| The Application of RFID Technology in Supporting the Process of Reliable Identification of Objects in Video Surveillance Systems. | 254 |
| Piotr Lubkowski, Dariusz Laskowski, and Marcin Polkowski | |
| Aspect-Oriented Management of Service Requests for Assurance of High Performance and Dependability | 264 |
| Paweł Lubomski, Paweł Pszczoliński, and Henryk Krawczyk | |
| Process of Mobile Application Development from the Security Perspective. | 277 |
| Aneta Majchrzycka and Aneta Poniszewska-Maranda | |
| Managing and Enhancing Performance Benchmarks. | 287 |
| Jakub Maleszewski and Janusz Sosnowski | |
| Reliability Optimization for Controller Placement in Software-Defined Networks | 298 |
| Jerzy Martyna | |
| Agent Approach to Network Systems Experimental Analysis in Case of Critical Situations. | 308 |
| Jacek Mazurkiewicz | |
| Reliability Assessment of Driving Systems of City Buses | 320 |
| Marek Młyńczak, Murat Muzdybayev, Alfiya Muzdybayeva, and Dinara Myrzabekova | |
| Testing the Significance of Parameters of Models Estimating Execution Time of Parallel Program Loops According to the Open MPI Standard | 331 |
| Łukasz Nozdrzykowski and Magdalena Nozdrzykowska | |

| | |
|--|-----|
| On Application of Regime-Switching Models for Short-Term Traffic Flow Forecasting | 340 |
| Dmitry Pavlyuk | |
| Critical Information Infrastructure Protection Model and Methodology, Based on National and NATO Study | 350 |
| Lachezar Petrov, Nikolai Stoianov, and Todor Tagarev | |
| The Method of Creating Players in the Marketing Strategy | 358 |
| Henryk Piech, Aleksandra Ptak, and Michal Saczek | |
| Principles of Mobile Walking Robot Control in Scope of Technical Monitoring Tasks | 368 |
| Oleksandr Radomskyi | |
| Computer Systems – Simple, Complicated or Complex | 383 |
| Dominik Strzałka | |
| Improving FPGA Implementations of BLAKE and BLAKE2 Algorithms with Memory Resources | 394 |
| Jarosław Sugier | |
| Assurance Case Patterns On-line Catalogue | 407 |
| Monika Szczygielska and Aleksander Jarzębowicz | |
| Information System as a Cause of Cargo Handling Process Disruption in Intermodal Terminal | 418 |
| Justyna Świeboda and Mateusz Zajac | |
| Anticipation Scheduling in Grid Virtual Organizations | 428 |
| Victor Toporkov, Dmitry Yemelyanov, Vadim Loginov, and Petr Potekhin | |
| Stability Enhancement Against Fluctuations in Complex Networks by Optimal Bandwidth Allocation | 439 |
| K.Y. Henry Tsang and K.Y. Michael Wong | |
| The Scope of the Collected Data for a Holistic Risk Assessment Performance in the Road Freight Transport Companies | 450 |
| Agnieszka Tubis and Sylwia Werbińska-Wojciechowska | |
| Language Processing Modelling Notation – Orchestration of NLP Microservices | 464 |
| Tomasz Walkowiak | |
| Type Variety Principle and the Algorithm of Strategic Planning of Diversified Portfolio of Electricity Generation Sources | 474 |
| Volodymyr Zaslavskyi and Maya Pasichna | |
| Author Index | 487 |

The Methodology of Studying of Active Traffic Management Module Self-oscillation Regime

Dmitry S. Kulyabov^{1,2(✉)}, Anna V. Korolkova¹, Tatyana R. Velieva¹,
Ekaterina G. Eferina¹, and Leonid A. Sevastianov^{1,3}

¹ Department of Applied Probability and Informatics,
Peoples' Friendship University of Russia (RUDN University),
6 Miklukho-Maklaya Street, Moscow 117198, Russian Federation
{kulyabov_ds,korolkova_av,sevastianov_la}@rudn.university,
trvelieva@gmail.com, eg.eferina@gmail.com

² Laboratory of Information Technologies, Joint Institute for Nuclear Research,
6 Joliot-Curie Street, Dubna, Moscow Region 141980, Russian Federation

³ Bogoliubov Laboratory of Theoretical Physics,
Joint Institute for Nuclear Research, 6 Joliot-Curie Street,
Dubna, Moscow Region 141980, Russian Federation

Abstract. Self-oscillating modes in computer networks control systems quite negatively affect the characteristics of these networks. The problem of finding the areas of self-oscillations is actual and important as the study of parameters of self-oscillations. Due to the significant nonlinearity of control characteristics, the study of the oscillatory modes presents certain difficulties. This paper describes the technique of research of self-oscillating modes on the basis of the control theory. This material is rather methodical than exploratory one.

Keywords: Traffic active management · Control theory · Self-oscillating mode

1 Introduction

While modeling technical systems with control it is often required to study characteristics of these systems. Also it is necessary to study the influence of system parameters on characteristics. In systems with control there is a parasitic phenomenon as self-oscillating mode. We carried out studies to determine the region of the self-oscillations emergence. However, the parameters of these oscillations were not investigated. In this paper, we propose to use the harmonic linearization method for this task. This method is used in control theory, but this branch of mathematics rarely used in classical mathematical modeling. The authors offer a methodological article in order to introduce this method to non-specialists.

2 The RED Congestion Adaptive Control Mechanism

To improve the performance of the channel it is necessary to optimize the queue management at the routers. One of possible approaches is the application of the Random Early Detection (RED) algorithm (see [1, 5, 9, 11, 14]).

The RED algorithm uses a weighted queue length as factor determining the probability of packet drop. As the average queue length grows, the probability of packets drop also increases (see (1)). The algorithm uses two threshold values of the average queue length to control drop function (Fig. 1):

$$p(\hat{Q}) = \begin{cases} 0, & 0 < \hat{Q} \leq Q_{\min}, \\ \frac{\hat{Q} - Q_{\min}}{Q_{\max} - Q_{\min}} p_{\max}, & Q_{\min} < \hat{Q} \leq Q_{\max}, \\ 1, & \hat{Q} > Q_{\max}. \end{cases} \quad (1)$$

Here $p(\hat{Q})$ — packet drop function (drop probability), \hat{Q} — exponentially-weighted moving average of the queue size average, Q_{\min} and Q_{\max} — thresholds for the weighted average of the queue length, p_{\max} — the maximum level of packet drop.

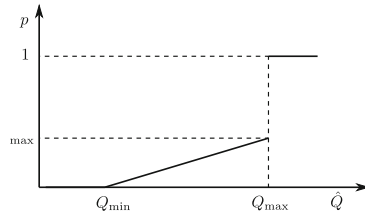


Fig. 1. RED packet drop function

The RED algorithm is quite effective due to simplicity of implementation in the network hardware, but it has a number of drawbacks. In particular, for some parameters values there is a steady oscillatory mode in the system, which negatively affects Quality of Service (QoS) indicators [10, 15, 19]. Unfortunately there are no clear selection criteria for RED parameters values, in which the system does not enter in self-oscillating mode.

To describe the RED algorithm we will use the following continuous model

$$\begin{cases} \dot{W}(t) = \frac{1}{T(Q,t)} - \frac{W(t)W(t-T(Q,t))}{2T(t-T(Q,t))} p(t-T(Q,t)); \\ \dot{Q}(t) = \frac{W(t)}{T(Q,t)} N(t) - C; \\ \dot{\hat{Q}}(t) = -w_q C \hat{Q}(t) + w_q C Q(t). \end{cases} \quad (2)$$

(see [4, 6, 7, 12, 13, 16, 17, 20]) with some simplifying assumptions:

- the model is written in the moments;
- the model describes only the phase of congestion avoidance for TCP Reno protocol;
- in the model the drop is considered only after reception of 3 consistent ACK confirmations.

In (2) the following notation is used:

- W — the average TCP window size;
- Q — the average queue size;
- \bar{Q} — the exponentially weighted moving average (EWMA) of the queue size average;
- C — the queue service intensity;
- T — full round-trip time; $T = T_p + \frac{Q}{C}$, where T_p — round-trip time for free network (excluding delays in hardware); $\frac{Q}{C}$ — the time which batch spent in the queue;
- N — number of TCP sessions;
- p — packet drop function.

3 Harmonic Linearization Method

The method of harmonic linearization is an approximate method. It is used for study of start-oscillation conditions and determination of the parameters of self-oscillations, for the analysis and evaluation of their sustainability, as well as for the study of forced oscillations. Harmonically-linearized system depends on the amplitudes and frequencies of periodic processes. The harmonic linearization differs from the common method of linearization (leading to purely linear expressions) and allows to explore the basic properties of nonlinear systems.

We will use the block-linear approach in control theory [3]. According to this approach, the original nonlinear system is linearized and divided into blocks. These blocks are characterized by the transfer function linking the input and output values. The method of harmonic linearization is used for systems of a certain structure (see Fig. 2). The system consists of linear part H_l and the nonlinear part, which is set by function $f(x)$. It is generally considered a static nonlinear element.

For the harmonic linearization method free movement mode (input $g(t) = 0$) is assumed. The free harmonic oscillations are applied to the input of the nonlinear element:

$$x(t) = A \sin(\omega t). \quad (3)$$

On the output of the nonlinear element $f(x)$ we get a periodic signal. Let's expand it in a Fourier series:

$$f(x) = \frac{a_0}{2} + \sum_{k=1}^{\infty} (a_k \sin(k\omega t) + b_k \cos(k\omega t)), \quad (4)$$

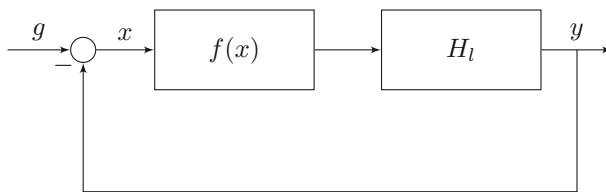


Fig. 2. Block structure of the system for the harmonic linearization method

where the coefficients of the Fourier series have the following form:

$$a_k = \frac{1}{\pi} \int_0^{2\pi} f(A \sin(\omega t)) \sin(k\omega t) d(\omega t);$$

$$b_k = \frac{1}{\pi} \int_0^{2\pi} f(A \sin(\omega t)) \cos(k\omega t) d(\omega t); \quad k = \overline{1, \infty}.$$

In this case we assume that in (4) $a_0 = 0$, in other words the constant component is absent.

The linear element is a low-pass filter, that is, when k is increasing the linear elements suppress higher harmonics. We will consider only the first harmonics. Then (4) will be presented in the form:

$$f(x) = a_1 \sin(\omega t) + b_1 \cos(\omega t), \quad (5)$$

where

$$a_1 = \frac{1}{\pi} \int_0^{2\pi} f(A \sin(\omega t)) \sin(\omega t) d(\omega t);$$

$$b_1 = \frac{1}{\pi} \int_0^{2\pi} f(A \sin(\omega t)) \cos(\omega t) d(\omega t).$$

From (3) you can write:

$$\sin(\omega t) = \frac{x}{A};$$

$$\cos(\omega t) = \frac{1}{A\omega} \frac{dx}{dt} = \frac{1}{A\omega} \frac{d}{dt} x. \quad (6)$$

Then we may rewrite (5) with respect (6):

$$f(x) = [\varkappa(A) + \frac{\varkappa'(A)}{\omega} \frac{d}{dt}]x = H_{nl}(A, \partial_t)x, \quad (7)$$

where $H_{nl}(A, \partial_t)$ — approximate transfer function of the nonlinear unit, $\varkappa(a)$ and $\varkappa'(a)$ are the harmonic linearization coefficients:

$$\varkappa(A) = \frac{a_1}{A} = \frac{1}{A\pi} \int_0^{2\pi} f(A \sin(\omega t)) \sin(\omega t) d(\omega t);$$

$$\varkappa'(A) = \frac{b_1}{A} = \frac{1}{A\pi} \int_0^{2\pi} f(A \sin(\omega t)) \cos(\omega t) d(\omega t). \quad (8)$$

After finding the coefficients of harmonic linearization for given nonlinear unit, it is possible to study the parameters of the oscillation mode. The existence of oscillation mode in a nonlinear system corresponds to the determination of oscillating boundary of stability for the linearized system. Then A and ω can be found by using stability criteria of linear systems (Mikhailov, Nyquist–Mikhailov, Routh–Hurwitz). Thus, the study of self-oscillation parameters can be done by one of the methods of determining the limits of stability of linear systems.

3.1 The Nyquist–Mikhailov Criterion

This criterion belongs to analytical and graphic criteria. It has remarkable graphical representation of the system behavior and regions of existence of the oscillatory mode.

The Nyquist-Mikhailov criterion – [18] allows to judge about the stability of the open-loop automatic control system by using Nyquist plot (amplitude-phase characteristic) of the open-loop system.

Make the substitutions $\partial_t \rightarrow i\omega$ and $s \rightarrow \partial_t \rightarrow i\omega$ in the transfer function. Undamped sinusoidal oscillations with constant amplitude are determined by passing the amplitude-phase characteristics of the open-loop system through the point $(-1, i0)$.

The characteristic function of the system is:

$$1 + H_o(i\omega) = 0,$$

$$H_o(i\omega) := H_l(i\omega)H_{nl}(A, i\omega).$$

where H_o — the transfer function of the open-loop system.

Thus:

$$H_l(i\omega)H_{nl}(A, i\omega) = -1. \quad (9)$$

Given by (7) from (9) the equality is obtained:

$$H_l(i\omega) = -\frac{1}{\varkappa(A) + i\varkappa'(A)}. \quad (10)$$

The left part of the Eq. (10) is the amplitude-phase characteristic of the linear unit, and the right part is the inverse of the amplitude-phase characteristic of the first harmonic non-linear level (with opposite sign). And the Eq. (10) is the equation of balance between the frequency and the amplitude.

This type of criterion is also called as a Goldfarb method.

Sometimes it is more convenient to write the Eq. (10) in the following form:

$$\varkappa(A) + i\varkappa'(A) = -\frac{1}{H_l(i\omega)}. \quad (11)$$

This type of criterion is also called as a Kochenburger method.

4 Harmonic Linearization of the Linearized RED Model

To rewrite the model (2) in the block-linear approach we need to linearize it. We will follow the article [6].

Let's write linearized system:

$$\begin{cases} \delta W(s) = -\frac{1}{s + \frac{N}{CT_f^2}(1+e^{-sT_f})} \frac{C^2 T_f}{2N^2} e^{-sT_f} \delta p(s); \\ \delta Q(s) = \frac{1}{s + \frac{1}{T_f}} \frac{N}{T_f} \delta W(s); \\ \delta \hat{Q}(s) = \frac{1}{1 + \frac{s}{w_q C}} \delta Q(s); \\ \delta p(s) = P_{\text{RED}} \frac{1}{1 + \frac{s}{w_q C}} \delta Q(s), \end{cases} \quad (12)$$

where the balance point is denoted by f index, variation is denoted by δ , and

$$P_{\text{RED}} := \begin{cases} 0, & 0 < \hat{Q} \leq Q_{\min}, \\ \frac{p_{\max}}{Q_{\max} - Q_{\min}}, & Q_{\min} < \hat{Q} \leq Q_{\max}, \\ 0, & \hat{Q} > Q_{\max}. \end{cases}$$

Based on (12) the block representation of the linearized RED model (Fig. 3) is constructed.

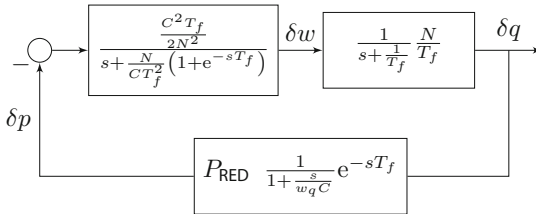


Fig. 3. Block representation of the linearized RED model

Let's reduce the block diagram of linearized model (Fig. 3) to the form required for harmonic linearization.

As a static nonlinear function we will use P_{RED} . The linear part is follows:

$$\begin{aligned} H_l &= \frac{1}{s + \frac{N}{CT_f^2}(1+e^{-sT_f})} \frac{C^2 T_f}{2N^2} e^{-sT_f} \times \frac{1}{s + \frac{1}{T_f}} \frac{N}{T_f} \times \frac{1}{1 + \frac{s}{w_q C}} \\ &= \frac{1}{s + \frac{N}{CT_f^2}(1+e^{-sT_f})} \frac{1}{s + \frac{1}{T_f}} \frac{1}{1 + \frac{s}{w_q C}} \frac{C^2}{2N} e^{-sT_f}. \end{aligned} \quad (13)$$

In the block representation the diagram from Fig. 3 will be as shown in Fig. 4.

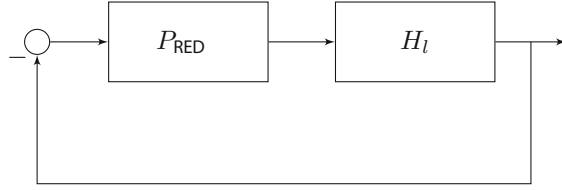


Fig. 4. Block representation of the linearized RED model for harmonic linearization

Let us compute the coefficients of harmonic linearization $\varkappa(a)$ and $\varkappa'(a)$ (8) for the static nonlinearity P_{RED} :

$$\begin{aligned}\varkappa(A) &= \frac{4}{A\pi} \int_0^{\pi/2} P_{\text{RED}}(A \sin(\omega t)) \sin(\omega t) d(\omega t); \\ \varkappa'(A) &= \frac{4}{A\pi} \int_0^{\pi/2} P_{\text{RED}}(A \sin(\omega t)) \cos(\omega t) d(\omega t).\end{aligned}$$

We will get:

$$\begin{aligned}\varkappa(A) &= \frac{4}{A\pi} \frac{p_{\max}}{Q_{\max} - Q_{\min}} \int_{\alpha_{\min}}^{\alpha_{\max}} \sin(\omega t) d(\omega t) \\ &= \frac{4}{A\pi} \frac{p_{\max}}{Q_{\max} - Q_{\min}} - \cos(\omega t) \Big|_{\alpha_{\min}}^{\alpha_{\max}} \frac{4}{A\pi} \frac{p_{\max} (\cos \alpha_{\min} - \cos \alpha_{\max})}{Q_{\max} - Q_{\min}}; \quad (14)\end{aligned}$$

$$\begin{aligned}\varkappa'(A) &= \frac{4}{A\pi} \frac{p_{\max}}{Q_{\max} - Q_{\min}} \int_{\alpha_{\min}}^{\alpha_{\max}} \cos(\omega t) d(\omega t) \\ &= \frac{4}{A\pi} \frac{p_{\max}}{Q_{\max} - Q_{\min}} \sin(\omega t) \Big|_{\alpha_{\min}}^{\alpha_{\max}} = \frac{4}{A\pi} \frac{p_{\max} (\sin \alpha_{\max} - \sin \alpha_{\min})}{Q_{\max} - Q_{\min}}. \quad (15)\end{aligned}$$

The values of \sin and \cos from integration limits α_{\min} and α_{\max} :

$$\begin{aligned}x = A \sin \alpha_{\min} = Q_{\min}, \quad \sin \alpha_{\min} &= \frac{Q_{\min}}{A}; \quad \cos \alpha_{\min} = \sqrt{1 - \frac{Q_{\min}^2}{A^2}}; \\ x = A \sin \alpha_{\max} = Q_{\max}, \quad \sin \alpha_{\max} &= \frac{Q_{\max}}{A}; \quad \cos \alpha_{\max} = \sqrt{1 - \frac{Q_{\max}^2}{A^2}}.\end{aligned} \quad (16)$$

Thus, from (14) and (15) with the help of (16) we will get:

$$\begin{aligned}\varkappa(A) &= \frac{4}{A\pi} \frac{p_{\max}}{Q_{\max} - Q_{\min}} \left(\sqrt{1 - \frac{Q_{\min}^2}{A^2}} - \sqrt{1 - \frac{Q_{\max}^2}{A^2}} \right); \\ \varkappa'(A) &= \frac{4}{A\pi} \frac{p_{\max}}{Q_{\max} - Q_{\min}} \frac{Q_{\max} - Q_{\min}}{A} = \frac{4p_{\max}}{A^2\pi}.\end{aligned} \quad (17)$$

Thus, from (10), (13) and (17) we may derive:

$$\begin{aligned} & \frac{1}{i\omega + \frac{N}{CT_f^2}(1 + e^{-i\omega T_f})} \frac{1}{i\omega + \frac{1}{T_f}} \frac{1}{1 + \frac{i\omega}{w_q C}} \frac{C^2}{2N} e^{-i\omega T_f} \\ &= -\frac{A\pi}{4p_{\max}} \left[\frac{1}{Q_{\max} - Q_{\min}} \left(\sqrt{1 - \frac{Q_{\min}^2}{A^2}} - \sqrt{1 - \frac{Q_{\max}^2}{A^2}} \right) + i\frac{1}{A} \right]^{-1}. \end{aligned} \quad (18)$$

For clarity, it is possible to plot parametric graphs on the complex plane separately for left $H_l(i, \omega)$ and right $-1/H_{nl}(A)$ parts of the Eq. (18) (of ω and A respectively) (see Figs. 5 and 6). The intersection of the curves gives the point of emergence of self-oscillations.

For the example of the calculation we have chosen the following parameters: $Q_{\min} = 100$ [packets], $Q_{\max} = 150$ [packets], $p_{\max} = 0.1$, $T_p = 0.0075$ s, $w_q = 0.002$, $C = 2000$ [packets]/s, $N = 60$ (the number of TCP sessions). As a result we obtained the following values for the amplitude and the cyclic frequency: $A = 1.89$ [packets], $\omega = 16.55s^{-1}$.

The traffic behavior can be demonstrated by using the standard computer networks simulation software NS-2 [2, 8]. For selected parameters we will get the

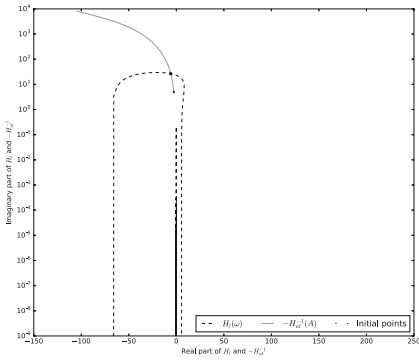


Fig. 5. Nyquist plot for system (18)

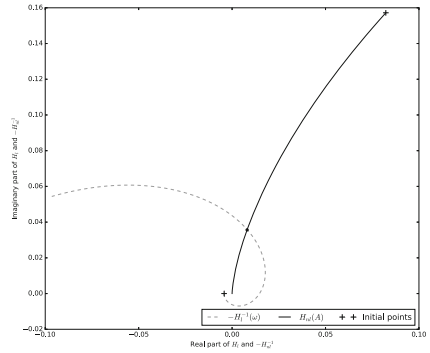


Fig. 6. Nyquist plot for system (11)

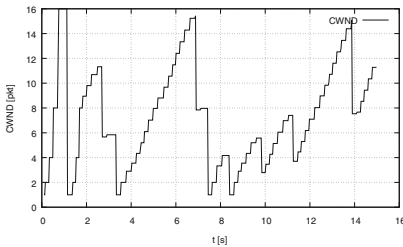


Fig. 7. A sliding window size changes at the source

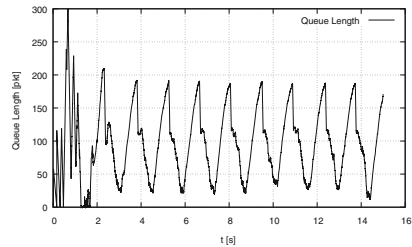


Fig. 8. A router's queue oscillation under RED control

graph of the window size change (at the traffic source) (Fig. 7) and oscillations of the instantaneous queue length at router under RED control (Fig. 8).

5 Conclusion

The authors demonstrated the technique of research of oscillatory modes of the systems with control. We tried to explain this technique for mathematicians unfamiliar with the formalism of the control theory. We plan to apply this technique to the study of a wide range of algorithms of traffic active control. Also it is interesting to compare these results with the previous results obtained for self-oscillation systems with control.

Acknowledgments. The work is partially supported by RFBR grants No's 15-07-08795 and 16-07-00556. Also the publication was financially supported by the Ministry of Education and Science of the Russian Federation (the Agreement No 02.A03.21.0008).

References

1. Adams, R.: Active queue management: a survey. *IEEE Commun. Surv. Tutorials* **15**(3), 1425–1476 (2013). doi:[10.1109/SURV.2012.082212.00018](https://doi.org/10.1109/SURV.2012.082212.00018)
2. Altman, E., Jiménez, T.: NS simulator for beginners. *Synth. Lect. Commun. Netw.* **5**(1), 1–184 (2012). doi:[10.2200/S00397ED1V01Y201112CNT010](https://doi.org/10.2200/S00397ED1V01Y201112CNT010)
3. Åström, K.J., Murray, R.M.: *Feedback Systems: An Introduction for Scientists and Engineers*, p. 408, USA (2008)
4. Brockett, R.: Stochastic analysis for fluid queueing systems. In: *Proceedings of the 38th IEEE Conference on Decision and Control* (Cat. No. 99CH36304), vol. 3, pp. 3077–3082. IEEE (1999). doi:[10.1109/CDC.1999.831407](https://doi.org/10.1109/CDC.1999.831407)
5. Floyd, S., Jacobson, V.: Random early detection gateways for congestion avoidance. *IEEE/ACM Trans. Netw.* **1**(4), 397–413 (1993). doi:[10.1109/90.251892](https://doi.org/10.1109/90.251892)
6. Holot, C.V.V., Misra, V., Towsley, D.: A control theoretic analysis of RED. In: *Proceedings of IEEE Conference on Computer Communications. Twentieth Annual Joint Conference of the IEEE Computer and Communications Society, INFOCOM 2001* (Cat. No. 01CH37213), vol. 3, pp. 1510–1519. IEEE (2001). doi:[10.1109/INFCOM.2001.916647](https://doi.org/10.1109/INFCOM.2001.916647)
7. Holot, C.V.V., Misra, V., Towsley, D.: On designing improved controllers for AQM routers supporting TCP flows. In: *Proceedings of IEEE Conference on Computer Communications. Twentieth Annual Joint Conference of the IEEE Computer and Communications Society, INFOCOM 2001*, (Cat. No. 01CH37213), vol. 3, pp. 1726–1734. IEEE (2001). doi:[10.1109/INFCOM.2001.916670](https://doi.org/10.1109/INFCOM.2001.916670)
8. Issariyakul, T., Hossain, E.: *Introduction to Network Simulator NS2*. Springer, New York (2012). doi:[10.1007/978-1-4614-1406-3](https://doi.org/10.1007/978-1-4614-1406-3). 9781461414
9. Jacobson, V.: Congestion avoidance and control. *ACM SIGCOMM Comput. Commun. Rev.* **18**(4), 314–329 (1988). doi:[10.1145/52325.52356](https://doi.org/10.1145/52325.52356)
10. Jenkins, A.: Self-oscillation. *Phys. Rep.* **525**(2), 167–222 (2013). doi:[10.1016/j.physrep.2012.10.007](https://doi.org/10.1016/j.physrep.2012.10.007)

11. Korolkova, A.V., Kulyabov, D.S., Chernoiyanov, A.I.: On the classification of RED algorithms. *Bull. Peoples' Friendship Univ. Russ. Ser. "Math. Inf. Sci. Phys."* (3), 34–46 (2009)
12. Korolkova, A.V., Kulyabov, D.S., Sevastianov, L.A.: Combinatorial and operator approaches to RED modeling. *Math. Model. Geom.* **3**(3), 1–18 (2015)
13. Korolkova, A.V., Velieva, T.R., Abaev, P.A., Sevastianov, L.A., Kulyabov, D.S.: Hybrid simulation of active traffic management. In: *Proceedings 30th European Conference on Modelling and Simulation*, pp. 685–691 (2016). doi:[10.7148/2016-0685](https://doi.org/10.7148/2016-0685)
14. Kushwaha, V., Gupta, R.: Congestion control for high-speed wired network: a systematic literature review. *J. Netw. Comput. Appl.* **45**, 62–78 (2014). doi:[10.1016/j.jnca.2014.07.005](https://doi.org/10.1016/j.jnca.2014.07.005)
15. Lautenschlaeger, W., Francini, A.: Global synchronization protection for bandwidth sharing TCP flows in high-speed links. In: *Proceedings of 16th International Conference on High Performance Switching and Routing, IEEE HPSR 2015, Budapest, Hungary* (2015)
16. Misra, V., Gong, W.B., Towsley, D.: Stochastic differential equation modeling and analysis of TCP-window size behavior. In: *Proceedings of Performance 1999* (1999)
17. Misra, V., Gong, W.B., Towsley, D.: Fluid-based analysis of a network of AQM routers supporting TCP flows with an application to RED. *ACM SIGCOMM Comput. Commun. Rev.* **30**(4), 151–160 (2000). doi:[10.1145/347057.347421](https://doi.org/10.1145/347057.347421)
18. Nyquist, H.: Regeneration theory. *Bell Syst. Techn. J.* **11**(1), 126–147 (1932). doi:[10.1002/j.1538-7305.1932.tb02344.x](https://doi.org/10.1002/j.1538-7305.1932.tb02344.x)
19. Ren, F., Lin, C., Wei, B.: A nonlinear control theoretic analysis to TCP-RED system. *Comput. Netw.* **49**(4), 580–592 (2005). doi:[10.1016/j.comnet.2005.01.016](https://doi.org/10.1016/j.comnet.2005.01.016)
20. Velieva, T.R., Korolkova, A.V., Kulyabov, D.S.: Designing installations for verification of the model of active queue management discipline RED in the GNS3. In: *6th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*, pp. 570–577. IEEE Computer Society (2015). doi:[10.1109/ICUMT.2014.7002164](https://doi.org/10.1109/ICUMT.2014.7002164)