

Founding Editors

Gerhard Goos

Karlsruhe Institute of Technology, Karlsruhe, Germany

Juris Hartmanis

Cornell University, Ithaca, NY, USA


Editorial Board Members

Elisa Bertino

Purdue University, West Lafayette, IN, USA

Wen Gao

Peking University, Beijing, China

Bernhard Steffen 

TU Dortmund University, Dortmund, Germany

Gerhard Woeginger 

RWTH Aachen, Aachen, Germany

Moti Yung

Columbia University, New York, NY, USA

More information about this series at <http://www.springer.com/series/7411>

Anna Tzanakaki · Manos Varvarigos ·
Raul Muñoz · Reza Nejabati ·
Noboru Yoshikane · Markos Anastasopoulos ·
Johann Marquez-Barja (Eds.)

Optical Network Design and Modeling


23rd IFIP WG 6.10 International Conference, ONDM 2019
Athens, Greece, May 13–16, 2019
Proceedings

Editors

Anna Tzanakaki
National and Kapodistrian
University of Athens
Athens, Greece

Raul Muñoz
Parc Mediterrani de la Tecnologia
Barcelona, Spain

Noboru Yoshikane
KDDI Research
Fujimino, Japan

Johann Marquez-Barja 
University of Antwerp - imec
Antwerp, Belgium

Manos Varvarigos
University of Patras
Patras, Greece

Reza Nejabati
Merchant Venturers Building
Bristol, UK

Markos Anastasopoulos
Merchant Venturers Building
Bristol, UK

ISSN 0302-9743 ISSN 1611-3349 (electronic)
Lecture Notes in Computer Science
ISBN 978-3-030-38084-7 ISBN 978-3-030-38085-4 (eBook)
<https://doi.org/10.1007/978-3-030-38085-4>

LNCS Sublibrary: SL5 – Computer Communication Networks and Telecommunications

© IFIP International Federation for Information Processing 2020, corrected publication 2020

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, expressed 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.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

It was an honor and a pleasure to welcome everyone to ONDM 2019, the 23rd edition of the Optical Network Design and Modelling conference, which was held at the National and Kapodistrian University of Athens, Greece, May 13–16, 2019.

ONDM 2019 focused on cutting-edge research in established areas of optical networking as well as their adoption in support of a wide variety of new services and applications. This involved the most recent trends in networking, including 5G and beyond, big data and network data analytics, cloud/edge computing, autonomic networking, artificial intelligence assisted networks, secure and resilient networks, etc., that drive the need for increased capacity, efficiency, flexibility, and adaptability in the functions that the network can perform.

In this context new disaggregated optical network architectures were discussed, exploiting and integrating novel multidimensional photonic technology solutions, as well as adopting open hardware and software platforms relying on software defined networking (SDN) and network function virtualization (NFV) to allow support of new business models and opportunities.

Some of the thematic areas that were covered include:

- Novel and multidimensional optical network architectures
- Optical network control, management, and orchestration, including SDN and NFV solutions
- Slicing, virtualization, and multitenancy techniques for optical networks
- Optical networking supporting low latency and high bandwidth network function virtualization
- Optical and wireless network convergence, including radio-over-fiber access networks
- Optical networks in support of intra-/inter-data center connectivity and cloud/edge computing
- Artificial intelligence and data analytics techniques for optical networks
- Advances in optical network modeling and optimization
- Routing and spectrum assignment in fixed and flex-grid optical networks
- Novel optical node designs including disaggregation and open optical line systems
- Optical network availability, resilience, survivability, security, and privacy
- Optical networking in support of vertical industries
- Field trials and interoperability demonstrations of optical networks
- Techno-economic studies of optical networks with emphasis on 5G consideration

Some of the key take away messages of the conference include:

- The importance of network user increases, as armed with increasingly-capable smart devices drive network level specifications and design/operation choices
 - The concept of service is being expanded beyond the traditional end-user context to a variety of end-user and operational services that are ICT or vertical industry related

- This imposes the requirement for newer infrastructures, e.g., 5G, 6G and beyond consisting of (optical) communication networks, (edge and cloud) data centers, distributed network functions, etc., in order to become more agile and facilitate more application-centric services with improved user experience
- Infrastructures equipped with additional/newer resources supporting higher bandwidth and lower latency focusing only on the lower layers of the protocol stack are not sufficient anymore
 - Instead, novel, flexible, open, and scalable architectural approaches supporting technology convergence, not only across network domains but also across network and compute/storage domains, involving inter- and intra-Data Center connectivity, are becoming essential
 - Methods developing real-time network-, service-, and application-centric analytics, able to process huge volumes of data, adopting artificial intelligence and machine-learning methods are needed to offer improved network and network service performance as well as user-experience, in support of the vision of future IT infrastructures
- Significant experimentation activities in real-life test-beds (5G UK) have already provided proof of principle demonstrations of the use and potential of optical networking in support of the new 5G and beyond network paradigm to facilitate end-user services with emphasis in improved experience and quality of leaving
- Significant attention has been put towards resilience and security considerations in the context of optical networking and the role optical technologies can play to facilitate more resilient and secure future network infrastructures

ONDM 2019 was a single-track conference. The conference included two workshops, one industrial panel, and one summer school co-organized by the H2020 5G PPP project 5G-PICTURE and the Erasmus Mundus programme SMARTNET:

- Workshop I: Optical Networking an enabler for 5G Solutions, Trials and Demonstrators
- Workshop II: Optical Intra- and Inter- Data Center Networks
- Industry Panel: 5G in 2020 and beyond: reality check, rollout plans and path ahead

Attendance: 90 Attendees

May 2019

Anna Tzanakaki
Manos Varvarigos
Raul Muñoz
Reza Nejabati
Noboru Yoshikane
Markos Anastasopoulos
Johann Marquez-Barja

The original version of the book was revised: The affiliation of the volume editor Johann Marquez-Barja has been corrected. The correction to the book is available at https://doi.org/10.1007/978-3-030-38085-4_56

Organization

General Chair

Anna Tzanakaki
National and Kapodistrian University of Athens,
Greece

General Co-chair

Manos Varvarigos
National Technical University of Athens, Greece

TPC Chairs

Raul Muñoz
Reza Nejabati
Noboru Yoshikane
CTTC, Spain
University of Bristol, UK
KDDI Research Inc., Japan

Local Organizing Committee

Hercules Avramopoulos
Dimitris Syvridis
National Technical University of Athens, Greece
National and Kapodistrian University of Athens,
Greece

Publicity Chair

Markos Anastasopoulos
University of Bristol, UK

EDAS and Publication Chair

Johann M. Marquez-Barja
University of Antwerpen and imec, Belgium

Steering Committee

Lena Wosinska
Piero Castoldi
Pablo Pavón Mariño
Tibor Cinkler
Marco Ruffini
Anna Tzanakaki
KTH Royal Institute of Technology, Sweden
SSSA, Italy
UPCT, Spain
BME, Hungary
Trinity College Dublin, Ireland
National and Kapodistrian University of Athens,
Greece

TPC Members

Slavisa Aleksic	Hochschule für Telekommunikation Leipzig, Germany
Markos Anastasopoulos	University of Bristol, UK
Bigomokero Bagula	University of the Western Cape, South Africa
Johan Bauwelinck	Ghent University and imec, Belgium
Andrea Bianco	Politecnico di Torino, Italy
Luiz Bonani	Universidade Federal do ABC, Brazil
Aparicio Carranza	New York City College of Technology, USA
Isabella Cerutti	Nokia Bell Labs, Italy
Jiajia Chen	KTH Royal Institute of Technology, Sweden
Kostas Christodoulopoulos	Nokia Bell Labs, Germany
Didier Colle	Ghent University and imec, Belgium
David Coudert	Université Côte d'Azur, Inria, CNRS, and I3S, France
Filippo Cugini	CNIT, Italy
Sandip Das	Trinity College Dublin, Ireland
Georgios Ellinas	University of Cyprus, Cyprus
Marija Furdek	KTH Royal Institute of Technology, Sweden
Maurice Gagnaire	Télécom Paris, France
Alessio Giorgetti	Scuola Superiore Sant'Anna, Italy
Philippe Gravey	Télécom Bretagne, France
Hiroaki Harai	National Institute of Information and Communications Technology, Japan
Hiroshi Hasegawa	Nagoya University, Japan
Yusuke Hirota	National Institute of Information and Communications Technology, Japan
Weisheng Hu	Shanghai Jiao Tong University, China
Brigitte Jaumard	Concordia University, Canada
Wojciech Kabacinski	Poznan University of Technology, Poland
Ezhan Karasan	Bilkent University, Turkey
Daniel Kilper	University of Arizona, USA
Ken-ichi Kitayama	The Graduate School for the Creation of New Photonics Industries, Japan
Nattapong Kitsuan	The University of Electro-Communications, Japan
Panagiotis Kokkinos	National Technical University of Athens, Greece
Yao Li	University of Arizona, USA
Andrew Lord	British Telecom, UK
Guido Maier	Politecnico di Milano, Italy
Ricardo Martinez	Centre Tecnològic de Telecomunicacions de Catalunya, Spain
Barbara Martini	CNIT, Italy
Xavier Masip-Bruin	Universitat Politècnica de Catalunya, Spain
Francesco Matera	Fondazione Ugo Bordoni, Italy
Paolo Monti	KTH Royal Institute of Technology, Sweden
Francesco Musumeci	Politecnico di Milano, Italy
Antonio Napoli	Infinera, Germany

Wenda Ni	Microsoft Azure Networking, USA
Jelena Pesic	Nokia Bell Labs, France
Johann M. Marquez-Barja	University of Antwerpen and imec, Belgium
Christina Politi	University of Peloponnese, Greece
Carla Raffaelli	University of Bologna, Italy
Moises Ribeiro	Universidade Federal do Espírito Santo, Brazil
Cristina Rottondi	Politecnico di Torino, Italy
George Rouskas	North Carolina State University, USA
Marc Ruiz	Universitat Politècnica de Catalunya, Spain
Dominic Schupke	Airbus, Germany
Motoyoshi Sekiya	Fujitsu Laboratories Ltd., Japan
Gangxiang Shen	Soochow University, China
Nina Skorin-Kapov	Centro Universitario de la Defensa San Javier, Spain
Salvatore Spadaro	Universitat Politècnica de Catalunya, Spain
Alexandros Stavdas	University of Peloponnese, Greece
Ravi Subrahmanyam	Invisage Technologies, USA
Suresh Subramaniam	The George Washington University, USA
Giuseppe Talli	Tyndall National Institute and University College Cork, Ireland
Takahito Tanimura	Fujitsu Laboratories Ltd., Japan
Maria Torres-Vega	Ghent University, Belgium
Dimitris Varoutas	University of Athens, Greece
Emmanouel Varvarigos	National Technical University of Athens and Computer Technology Institute, Greece
Luis Velasco	Universitat Politècnica de Catalunya, Spain
Vinod Vokkarane	University of Massachusetts Lowell, USA
Krzysztof Wajda	AGH University of Science and Technology, Poland
Elaine Wong	The University of Melbourne, Australia
Lena Wosinska	KTH Royal Institute of Technology, Sweden
Sugang Xu	National Institute of Information and Communications Technology, Japan
Shuangyi Yan	University of Bristol, UK
Xin Yin	Ghent University and imec, Belgium
Fen Zhou	University of Avignon, France
Zuqing Zhu	University of Science and Technology of China, China
Moshe Zukerman	City University of Hong Kong, Hong Kong, China

Contents

Regular Papers

Hybrid Backup Resource Optimization for VNF Placement Over Optical Transport Networks	3
<i>João Pedro and António Eira</i>	
Software-Defined Reconfigurability, White Boxes, and Abstraction.	15
<i>Nicola Sambo, Alessio Giorgetti, Andrea Sgambelluri, Piero Castoldi, and Luca Valcarenghi</i>	
Embedding Virtual Networks in Flexible Optical Networks with Sliceable Transponders	26
<i>Juzi Zhao and Suresh Subramaniam</i>	
Virtualized Controller Placement for Multi-domain Optical Transport Networks.	39
<i>Sabidur Rahman, Tanjila Ahmed, Sifat Ferdousi, Partha Bhaumik, Pulak Chowdhury, Massimo Tornatore, Goutam Das, and Biswanath Mukherjee</i>	
End-to-End Network Slicing in Support of Latency-Sensitive 5G Services . . .	51
<i>Rafael Montero, Fernando Agraz, Albert Pagès, and Salvatore Spadaro</i>	
The Impact of the Optical Network on 5G – The Metro-Haul Project	62
<i>Andrew Lord, Albert Rafel, Michael Parker, and Adrian Farrel</i>	
Availability-Guaranteed Slice Provisioning in Wireless-Optical Broadband Access Networks Supporting Mobile Edge Computing.	70
<i>Ke Chen, Gangxiang Shen, Shuiping Jie, Boping Jiang, and Sanjay K. Bose</i>	
DU/CU Placement for C-RAN over Optical Metro-Aggregation Networks . . .	82
<i>Hao Yu, Francesco Musumeci, Jiawei Zhang, Yuming Xiao, Massimo Tornatore, and Yuefeng Ji</i>	
Adaptive Function Chaining for Efficient Design of 5G Xhaul	94
<i>Bahare M. Khorsandi, Didier Colle, Wouter Tavernier, and Carla Raffaelli</i>	

Dynamic Softwarised RAN Function Placement in Optical Data Centre Networks	108
<i>Nikolaos Gkatzios, Markos Anastasopoulos, Anna Tzanakaki, and Dimitra Simeonidou</i>	
Techno-Economic Aspects of 5G Transport Network Deployments	118
<i>I. Mesogiti, E. Theodoropoulou, G. Lyberopoulos, F. Setaki, K. Filis, A. Di Giglio, A. Percelsi, and Anna Tzanakaki</i>	
RHODA Topology Configuration Using Bayesian Optimization	130
<i>Maotong Xu, Min Tian, Eytan Modiano, and Suresh Subramaniam</i>	
Dynamic Abstraction of Optical Networks with Machine Learning Technologies.	142
<i>Shuangyi Yan, Zhengguang Gao, Rui Wang, Alex Mavromatis, Reza Nejabati, and Dimitra Simeonidou</i>	
Novel P-Cycle Selection Algorithms for Elastic Optical Networks.	154
<i>Rujia Zou and Suresh Subramaniam</i>	
How to Survive Targeted Fiber Cuts: A Game Theoretic Approach for Resilient SDON Control Plane Design	168
<i>Jing Zhu, Marija Furdek, Carlos Natalino, Lena Wosinska, and Zuqing Zhu</i>	
Joint Fronthaul Optimization and SDN Controller Placement in Dynamic 5G Networks.	181
<i>Victoria-Maria Alevizaki, Markos Anastasopoulos, Anna Tzanakaki, and Dimitra Simeonidou</i>	
3-Stage Hierarchical Quality of Service for Multi-tenant Passive Optical Networks	193
<i>Frank Slyne, Bruno Cornaglia, Marco Boselli, and Marco Ruffini</i>	
Machine Learning Assisted Optical Network Resource Scheduling in Data Center Networks	204
<i>Hongxiang Guo, Cen Wang, Yinan Tang, Yong Zhu, Jian Wu, and Yong Zuo</i>	
Machine Learning Assisted Quality of Transmission Estimation and Planning with Reduced Margins	211
<i>Konstantinos Christodoulopoulos, Ippokratis Sartzetakis, Polizois Soumplis, and Emmanouel (Manos) Varvarigos</i>	
Network Programmability and Automation in Optical Networks	223
<i>Ricard Vilalta, Ramon Casellas, Ricardo Martínez, and Raul Muñoz</i>	

Fragmentation Metrics in Spectrally-Spatially Flexible Optical Networks	235
<i>Piotr Lechowicz, Massimo Tornatore, Adam Włodarczyk, and Krzysztof Walkowiak</i>	
Intrinsically Resilient Optical Backbones: An Efficient Ring-Based Interconnection Paradigm	248
<i>Marcia H. M. Paiva, Gilles Caporossi, Moises R. N. Ribeiro, and Marcelo E. V. Segatto</i>	
Experimental Evaluation of Dynamic Resource Orchestration in Multi-layer (Packet over Flexi-Grid Optical) Networks	261
<i>Silvia Fichera, Barbara Martini, Ricardo Martínez, Ramon Casellas, Ricard Vilalta, Raul Muñoz, and Piero Castoldi</i>	
Optics for Disaggregating Data Centers and Disintegrating Computing	274
<i>Nikos Terzenidis, Miltiadis Moralis-Pegios, Stelios Pitris, Charoula Mitsolidou, George Mourgias-Alexandris, Apostolis Tsakyridis, Christos Vagionas, Konstantinos Vyrsoinos, Theoni Alexoudi, and Nikos Pleros</i>	
Simplifying Optical DCN Fabrics with Blocking Space Switching and Wavelength-Constrained WDM.	286
<i>Konstantinos Kontodimas, Kostas Christodouloupoulos, and Emmanouel Varvarigos</i>	
Dual-Layer Locality-Aware Optical Interconnection Architecture for Latency-Critical Resource Disaggregation Environments	299
<i>Nikos Terzenidis, Miltiadis Moralis-Pegios, Theoni Alexoudi, Stelios Pitris, Konstantinos Vyrsoinos, and Nikos Pleros</i>	
Network-Wide Localization of Optical-Layer Attacks	310
<i>Marija Furdek, Vincent W. S. Chan, Carlos Natalino, and Lena Wosinska</i>	
Analytical Modeling of Survivable Anycast Communication in Optical Networks	323
<i>Yan Cui and Vinod M. Vokkarane</i>	
Network Coding for Security Against Eavesdropping Attacks in Elastic Optical Networks	336
<i>Giannis Savva, Konstantinos Manousakis, and Georgios Ellinas</i>	
Resilient Cloud-RANs Adopting Network Coding	349
<i>Arash Farhadi Beldachi, Markos Anastasopoulos, Alexandros Manolopoulos, Anna Tzanakaki, Reza Nejabati, and Dimitra Simeondou</i>	

**A Novel Carrier-Cooperation Scheme with an Incentive for Offering
Emergency Lightpath Support in Disaster Recovery. 362**
*Sugang Xu, Noboru Yoshikane, Naoki Miyata, Masaki Shiraiwa,
Takehiro Tsuritani, Xiaocheng Zhang, Yoshinari Awaji,
and Naoya Wada*

State-of-the-Art and Future of Submarine Cable System Technology 377
Hidenori Takahashi

Modeling Long-Haul Optical Networks with Quasi-single-mode Fibers 389
Ioannis Roudas, Xin Jiang, and Luis Miranda

**Crosstalk Mitigation in Long-Reach Multicore Fiber Communication
Systems Using RKHS Based Nonlinear Equalization 398**
Sandesh Jain, Anuj Agrawal, Vimal Bhatia, and Shashi Prakash

Physical Layer Security in Optical Networks 412
Dimitris Syvridis, Evangelos Pikasis, and Charidimos Chaintoutis

**A Gated Service MAC Protocol for 5G Fiber-Wireless Cloud-Radio
Access Networks. 425**
*Agapi Mesodiakaki, Pavlos Maniotis, Georgios Kalfas,
Christos Vagionas, John Vardakas, Elli Kartsakli,
Angelos Antonopoulos, Eftychia Datsika, Christos Verikoukis,
and Nikos Pleros*

**12 Gb/s Multiband Fiber-Wireless Link Using Coherent IFoF and V-band
mmWave Radio 437**
*Nikos Argyris, Giannis Giannoulis, Konstantina Kanta,
Panagiotis Toumasis, Dimitrios Apostolopoulos,
and Hercules Avramopoulos*

System Innovations in Inter Data Center Transport Networks 444
*Loukas Paraschis, Harald Bock, Parthiban Kandappan,
Bernd Sommerkorn-Krombholz, Joao Pedro, Abhinava Sadasivarao,
Sharfuddin Syed, Jeff Rahn, Paul Doolan, and Biao Lu*

**SDN Control of Disaggregated Optical Networks with OpenConfig
and OpenROADM 452**
Ramon Casellas, Ricard Vilalta, Ricardo Martínez, and Raúl Muñoz

Poster Papers

Self-learning Routing for Optical Networks 467
Yue-Cai Huang, Jie Zhang, and Siyuan Yu

Deterministic Contention Management for Low Latency Cloud RAN over an Optical Ring	479
<i>Dominique Barth, Maël Guiraud, and Yann Strozecki</i>	
Resource Analysis and Cost Modeling for End-to-End 5G Mobile Networks	492
<i>Hilary Frank, Rodrigo S. Tessinari, Yuqing Zhang, Zhengguang Gao, Carlos Colman Meixner, Shuangyi Yan, and Dimitra Simeonidou</i>	
Analog IFoF/mmWave 5G Optical Fronthaul Architecture for Hot-Spots Using Multi-channel OFDM-Based WDM Signals.	504
<i>Charoula Mitsolidou, Christos Vagionas, Agapi Mesodiakaki, Pavlos Maniotis, George Kalfas, Chris G. H. Roeloffzen, Paulus W. L. van Dijk, Ruud M. Oldenbeuving, Amalia Miliou, and Nikos Pleros</i>	
Hybrid and Optical Packet Switching Supporting Different Service Classes in Data Center Network	516
<i>Artur Minakhmetov, Cédric Ware, and Luigi Iannone</i>	
Reduction of Delay Overfulfillment in IP-over-DWDM Transport Networks	528
<i>Uwe Bauknecht, Tobias Enderle, and Arthur Witt</i>	
Design of a Real-Time DSP Engine on RF-SoC FPGA for 5G Networks. . . .	540
<i>Vasileios Kitsakis, Konstantina Kanta, Ioannis Stratakos, Giannis Giannoulis, Dimitrios Apostolopoulos, George Lentaris, Hercules Avramopoulos, Dimitrios Soudris, and Dionysios I. Reisis</i>	
Performance of Underwater Wireless Optical Link Under Weak Turbulence and Pointing Errors Using Heterodyne QAM Technique	552
<i>Argyris N. Stassinakis, Hector E. Nistazakis, George K. Varotsos, and George S. Tombras</i>	
MCF Skew Estimation at the Receiver for ARoF Antenna Beamforming	560
<i>Thomas Nikas, Evangelos Pikasis, Sotiris Karabetzos, and Dimitris Syvridis</i>	
Core Arrangement Based Spectrum-Efficient Path Selection in Core-Continuity Constrained SS-FONs.	570
<i>Anuj Agrawal, Vimal Bhatia, and Shashi Prakash</i>	
Topology and Failure Modeling for Optical Network Resilience Analysis Against Earthquakes	584
<i>Anuj Agrawal, Vimal Bhatia, and Shashi Prakash</i>	

A Performance Analysis of Supervised Learning Classifiers for QoT Estimation in ROADM-Based Networks 598
Alan A. Diaz-Montiel and Marco Ruffini

Programmable Flex-E and X-Ethernet Networks for Traffic Isolation in Multi-tenant Environments 610
Kostas Katsalis and Rixin Li

Q-Learning Based Joint Allocation of Fronthaul and Radio Resources in Multiwavelength-Enabled C-RAN 623
Ahmed Mohammed Mikaeil and Weisheng Hu

Advanced Interconnect Technologies 635
Christina (Tanya) Politi, Dimitris Alexandropoulos, and Dimitra Simeonidou

Supporting Diverse Customers and Prioritized Traffic in Next-Generation Passive Optical Networks 645
Naureen Hoque and Byrav Ramamurthy

Correction to: Optical Network Design and Modeling C1
Anna Tzanakaki, Manos Varvarigos, Raul Muñoz, Reza Nejabati, Noboru Yoshikane, Markos Anastasopoulos, and Johann Marquez-Barja

Author Index 659