

COMMUNICATION NETWORKS AND SERVICE MANAGEMENT IN THE ERA OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Edited by

Nur Zincir-Heywood | Marco Mellia | Yixin Diao




IEEE PRESS



**IEEE Press Series
on Networks
and Services
Management**

Veli Sahin and
Mehmet Ulema, *Series Editors*

WILEY

Table of Contents

[Cover](#)

[IEEE Press](#)

[Title Page](#)

[Copyright](#)

[Editor Biographies](#)

[List of Contributors](#)

[Preface](#)

[Acknowledgments](#)

[Acronyms](#)

[Part I: Introduction](#)

[1 Overview of Network and Service Management](#)

[1.1 Network and Service Management at Large](#)

[1.2 Data Collection and Monitoring Protocols](#)

[1.3 Network Configuration Protocol](#)

[1.4 Novel Solutions and Scenarios](#)

[Bibliography](#)

[2 Overview of Artificial Intelligence and Machine Learning](#)

[2.1 Overview](#)

[2.2 Learning Algorithms](#)

[2.3 Learning for Network and Service Management](#)

[Bibliography](#)

[Note](#)

[Part II: Management Models and Frameworks](#)

3 Managing Virtualized Networks and Services with Machine Learning

3.1 Introduction

3.2 Technology Overview

3.3 State-of-the-Art

3.4 Conclusion and Future Direction

Bibliography

4 Self-Managed 5G Networks¹

4.1 Introduction

4.2 Technology Overview

4.3 5G Management State-of-the-Art

4.4 Conclusions and Future Directions

Bibliography

Notes

5 AI in 5G Networks: Challenges and Use Cases

5.1 Introduction

5.2 Background

5.3 Case Studies

5.4 Conclusions and Future Directions

Bibliography

Note

6 Machine Learning for Resource Allocation in Mobile Broadband Networks

6.1 Introduction

6.2 ML in Wireless Networks

6.3 ML-Enabled Resource Allocation

6.4 Conclusion and Future Directions

Bibliography

Note

7 Reinforcement Learning for Service Function Chain Allocation in Fog Computing

7.1 Introduction

7.2 Technology Overview

7.3 State-of-the-Art

7.4 A RL Approach for SFC Allocation in Fog Computing

7.5 Evaluation Setup

7.6 Results

7.7 Conclusion and Future Direction

Bibliography

Note

Part III: Management Functions and Applications

8 Designing Algorithms for Data-Driven Network Management and Control: State-of-the-Art and Challenges¹

8.1 Introduction

8.2 Technology Overview

8.3 Data-Driven Algorithm Design: State-of-the-Art

8.4 Future Direction

8.5 Summary

Acknowledgments

Bibliography

Note

9 AI-Driven Performance Management in Data-Intensive Applications

9.1 Introduction

[9.2 Data-Processing Frameworks](#)

[9.3 State-of-the-Art](#)

[9.4 Conclusion and Future Direction](#)

[Bibliography](#)

[Notes](#)

[10 Datacenter Traffic Optimization with Deep Reinforcement Learning](#)

[10.1 Introduction](#)

[10.2 Technology Overview](#)

[10.3 State-of-the-Art: AuTO Design](#)

[10.4 Implementation](#)

[10.5 Experimental Results](#)

[10.6 Conclusion and Future Directions](#)

[Bibliography](#)

[Notes](#)

[11 The New Abnormal: Network Anomalies in the AI Era](#)

[11.1 Introduction](#)

[11.2 Definitions and Classic Approaches](#)

[11.3 AI and Anomaly Detection](#)

[11.4 Technology Overview](#)

[11.5 Conclusions and Future Directions](#)

[Bibliography](#)

[Notes](#)

[12 Automated Orchestration of Security Chains Driven by Process Learning*](#)

[12.1 Introduction](#)

[12.2 Related Work](#)

[12.3 Background](#)

[12.4 Orchestration of Security Chains](#)

[12.5 Learning Network Interactions](#)

[12.6 Synthesizing Security Chains](#)

[12.7 Verifying Correctness of Chains](#)

[12.8 Optimizing Security Chains](#)

[12.9 Performance Evaluation](#)

[12.10 Conclusions](#)

[Bibliography](#)

[Notes](#)

[13 Architectures for Blockchain-IoT Integration¹](#)

[13.1 Introduction](#)

[13.2 Blockchain-IoT Integration \(BIoT\)](#)

[13.3 BIoT Architectures](#)

[13.4 Summary and Considerations](#)

[Bibliography](#)

[Note](#)

[Index](#)

[End User License Agreement](#)

List of Tables

Chapter 3

[Table 3.1 Summary of the state-of-the-art for virtual network embedding.](#)

[Table 3.2 Summary of the state-of-the-art for ML-based placement in NFV.](#)

[Table 3.3 Summary of the state-of-the-art for ML-based scaling in NFV.](#)

[Table 3.4 Summary of the state-of-the-art for ML-based admission control app...](#)

[Table 3.5 Summary of the state-of-the-art for ML-based resource allocation a...](#)

Chapter 5

[Table 5.1 Categorization of covered use cases.](#)

[Table 5.2 Impact of including different monitoring types on QoE estimation a...](#)

Chapter 6

[Table 6.1 Summary of ML techniques.](#)

[Table 6.2 Machine learning-based power control.](#)

[Table 6.3 blackMachine-learning based scheduling.](#)

[Table 6.4 Machine learning-based user association.](#)

[Table 6.5 Machine learning-based spectrum allocation.](#)

Chapter 7

[Table 7.1 Variables used for the minimization of the overall system cost.](#)

[Table 7.2 A sample fraction of the observation space of the gym-fog environm...](#)

[Table 7.3 A sample fraction of the action space of the gym-fog environment.](#)

[Table 7.4 The reduced observation space of the gym-fog environment.](#)

[Table 7.5 The hardware configuration of each node.](#)

[Table 7.6 The gym-fog environment configuration.](#)

[Table 7.7 The MILP model execution time.](#)

Chapter 8

[Table 8.1 Node and graph features used for problem representation and learni...](#)

[Table 8.2 provides overview of research work, general optimization problems ...](#)

[Table 8.3 overviewing networking research work, general optimization problem...](#)

Chapter 9

[Table 9.1 Summary of the key characteristics of data-processing platform.](#)

[Table 9.2 Summary of the AI techniques considered for performance management...](#)

Chapter 11

[Table 11.1 Summary of reviewed papers.](#)

[Table 11.2 Summary of the reviewed tools.](#)

Chapter 12

[Table 12.1 The set of Android applications considered for evaluation.](#)

[Table 12.2 Number of rules for combined chains.](#)

[Table 12.3 Accuracy of chains generated for protecting applications.](#)

Chapter 13

[Table 13.1 Performance of selected cryptographic functions on different IoT ...](#)

List of Illustrations

Chapter 1

[Figure 1.1 Network and service management at large.](#)

[Figure 1.2 Example of monitoring architecture.](#)

[Figure 1.3 The SDN architecture.](#)

[Figure 1.4 Network functions virtualization architecture.](#)

Chapter 2

[Figure 2.1 Supervised learning model.](#)

[Figure 2.2 Unsupervised learning model.](#)

[Figure 2.3 Reinforcement learning model.](#)

Chapter 3

[Figure 3.1 Technologies for virtualizing network functions with examples.](#)

[Figure 3.2 Link virtualization technologies with examples.](#)

[Figure 3.3 Examples of network slices.](#)

Chapter 4

[Figure 4.1 Slicing and prioritization of 5G network traffic. An eHealth netw...](#)

[Figure 4.2 O-RAN high-level architecture.](#)

[Figure 4.3 vrAIn's control loop.](#)

[Figure 4.4 5G-PPP network architecture.](#)

Chapter 5

[Figure 5.1 Overview of AI/ML use cases in a service-aware 5G integrated netw...](#)

[Figure 5.2 Possible framework for ML integration in 5G.](#)

[Figure 5.3 Overview of the prediction process.](#)

[Figure 5.4 Mean per class accuracy on the testing set when using different a...](#)

[Figure 5.5 Components of the QoE management framework.](#)

Chapter 6

[Figure 6.1 Brief overview of ML techniques.](#)

Chapter 7

[Figure 7.1 High-level view of a fog computing environment \[6\].](#)

[Figure 7.2 An example of a service function chaining deployment \[14\].](#)

[Figure 7.3 The representation schema of most RL scenarios.](#)

[Figure 7.4 The fog-cloud infrastructure for the gym-fog environment evaluati...](#)

[Figure 7.5 The OpenAi gym environment structure.](#)

[Figure 7.6 The accumulated reward and the cost difference for the static use...](#)

[Figure 7.7 The percentage of accepted requests for the static scenario.](#)

[Figure 7.8 The execution time of each episode run.](#)

[Figure 7.9 The accumulated reward and the cost difference for the dynamic ca...](#)

[Figure 7.10 The percentage of accepted requests for the dynamic scenario.](#)

Chapter 8

[Figure 8.1 Comparison between \(a\) traditional and \(b\) ML/AI-based approaches...](#)

[Figure 8.2 Problem instances are first represented as graph. The graph is th...](#)

Chapter 9

[Figure 9.1 Comparison between Bayesian optimization and random search to rea...](#)

[Figure 9.2 A taxonomy of anomaly detection techniques generalizing the ones ...](#)

[Figure 9.3 The performance of ANNs models that is trained with training data...](#)

[Figure 9.4 Streaming workload in a simulated experiment \(a\) and average rewa...](#)

Chapter 10

[Figure 10.1 A general reinforcement learning setting using neural network as...](#)

[Figure 10.2 Current DRL systems are insufficient.](#)

[Figure 10.3 AuTO overview.](#)

[Figure 10.4 Multi-level feedback queuing.](#)

[Figure 10.5 AuTO: A four-queue example.](#)

[Figure 10.6 Comparison of deep stochastic and deep deterministic policies.](#)

[Figure 10.7 Testbed topology.](#)

[Figure 10.8 Traffic distributions in evaluation.](#)

[Figure 10.9 Homogeneous traffic: Average and p99 FCT.](#)

[Figure 10.10 Spatially heterogeneous traffic: Average and p99 FCT.](#)

[Figure 10.11 Dynamic scenarios: average FCT.](#)

[Figure 10.12 Dynamic scenarios: p99 FCT.](#)

[Figure 10.13 MLFQ thresholds from sRLA vs. optimal thresholds.](#)

[Figure 10.14 Average FCT using MLFQ thresholds from sRLA vs. optimal thresho...](#)

[Figure 10.15 p99 FCT using MLFQ thresholds from sRLA vs. optimal thresholds....](#)

[Figure 10.16 Load balancing using IRLA \(PG algorithm\): difference in number ...](#)

[Figure 10.17 CS response latency: Traces from four runs.](#)

[Figure 10.18 CS response latency: Scaling short flows \(\$m_s\$ \).](#)

Chapter 11

[Figure 11.1 A taxonomy for anomaly detection problems and techniques.](#)

[Figure 11.2 Examples of anomaly macro-categories. \(a\) Pointwise; \(b\) Context...](#)

[Figure 11.3 Example of deep neural network with four hidden layers.](#)

[Figure 11.4 Basic autoencoder structure.](#)

[Figure 11.5 Basic generative adversarial network architecture.](#)

Chapter 12

[Figure 12.1 Example of a Kinetic control plane automaton.](#)

[Figure 12.2 Security chain orchestrator integrated into a SDN infrastructure...](#)

[Figure 12.3 Different steps of the proposed methodology.](#)

[Figure 12.4 Inferred Markov chain of the Pokemon Go Android application.](#)

[Figure 12.5 A toy security chain in pyretic and its encoding as a constraint...](#)

[Figure 12.6 Overhead in terms of bandwidth introduced by security chain depl...](#)

Chapter 13

[Figure 13.1 IoT adoption estimation for the 2017-2030 period \[1\].](#)

[Figure 13.2 Categories of BIoT risks.](#)

[Figure 13.3 BC-IoT integration \(BIoT\) metrics.](#)

[Figure 13.4 BC and IoT integration models \[22\]. \(a\) IoT-IoT, \(b\) IoT-Blockch...](#)

[Figure 13.5 An SDN-enabled fog and cloud-based BIoT architecture.](#)

[Figure 13.6 BIIT 1.0 architecture.](#)

IEEE Press
445 Hoes Lane
Piscataway, NJ 08854

IEEE Press Editorial Board

Ekram Hossain, *Editor in Chief*

Jón Atli
Benediktsson

Xiaoou Li

Jeffrey Reed

Anjan Bose

Lian Yong

Diomidis Spinellis

David Alan Grier

Andreas Molisch

Sarah Spurgeon

Elya B. Joffe

Saeid

Ahmet Murat

Nahavandi

Tekalp

Communication Networks and Service Management in the Era of Artificial Intelligence and Machine Learning

Edited by

Nur Zincir-Heywood, Marco Mellia, and Yixin Diao



**IEEE Press
Series on
Networks and
Services Management**

**Dr. Veli Sahin and
Dr. Mehmet Ulema, *Series Editors***



IEEE PRESS

WILEY

Copyright © 2021 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permission>.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data:

Names: Zincir-Heywood, Nur, editor. | Mellia, Marco, editor. | Diao, Yixin, 1970- editor.

Title: Communication networks and service management in the era of artificial intelligence and machine learning / edited by Nur Zincir-Heywood, Marco Mellia, and Yixin Diao.

Description: Hoboken, New Jersey : Wiley-IEEE Press, [2021] | Series: IEEE Press series on networks and service management | Includes

bibliographical references and index.

Identifiers: LCCN 2021032407 (print) | LCCN 2021032408 (ebook) | ISBN 9781119675501 (cloth) | ISBN 9781119675440 (adobe pdf) | ISBN 9781119675518 (epub)

Subjects: LCSH: Computer networks. | Artificial intelligence. | Machine learning.

Classification: LCC TK5105.5 .C5998 2021 (print) | LCC TK5105.5 (ebook) | DDC 004.6-dc23

LC record available at <https://lccn.loc.gov/2021032407>

LC ebook record available at <https://lccn.loc.gov/2021032408>

Cover Design: Wiley

Cover Image: © Bill Donnelley/WT Design

Editor Biographies

Nur Zincir-Heywood received the PhD in Computer Science and Engineering in 1998. She is a full professor at the Faculty of Computer Science, Dalhousie University, Canada, where she directs the NIMS Research Lab on Network Information Management and Security. Her research interests include machine learning and artificial intelligence for cyber security, network, systems, and information analysis, topics on which she has published over 200 fully reviewed papers. She is a recipient of several best paper awards as well as the supervisor for the recipient of the IFIP/IEEE IM 2013 Best PhD Dissertation Award in Network Management. She is the co-editor of the book “Recent Advances in Computational Intelligence in Defense and Security” and co-author of the book “Nature-inspired Cyber Security and Resiliency: Fundamentals, Techniques, and Applications.” She is an Associate Editor of the IEEE Transactions on Network and Service Management and Wiley's International Journal of Network Management. She has been a co-organizer for the IEEE/IFIP International Workshop on Analytics for Network and Service Management since 2016. She served as Technical Program Co-chair for the IEEE Symposium on Computational Intelligence for Security and Defence Applications in 2011, International Conference on Network Traffic Measurement and Analysis in 2018, International Conference on Network and Service Management in 2019, and she served as General Co-chair for the International Conference on Network and Service Management in 2020. Professor Zincir-Heywood's research record was recognized with the title of Dalhousie University Research Professor in 2021.

Marco Mellia graduated with PhD in Electronic and Telecommunication Engineering in 2001. He is a full professor at Politecnico di Torino, Italy, where he coordinates the SmartData@PoliTO center on Big Data, Machine Learning and Data Science. In 2002, he visited the Sprint Advanced Technology Laboratories in Burlingame, CA, working at the IP Monitoring Project (IPMON). In 2011, 2012, and 2013, he collaborated with Narus Inc. in Sunnyvale, CA, working on traffic monitoring and cyber-security system design. In 2015 and 2016, he visited Cisco Systems in San Jose, CA, working on the design of cloud monitoring platforms. Professor Mellia has co-authored over 250 papers published in international journals and presented in leading conferences, all of them in the area of communication networks. He won the IRTF ANR Prize at IETF-88 and best paper awards at IEEE P2P'12, ACM CoNEXT'13, IEEE ICDCS'15. He participated in the program committees of several conferences including ACM SIGCOMM, ACM CoNEXT, ACM IMC, IEEE Infocom, IEEE Globecom, and IEEE ICC. He is the Area Editor of ACM CCR, IEEE Transactions on Network and Service Management and Elsevier Computer Networks. He is a Fellow of IEEE. His research interests are in the area of Internet monitoring, users' characterization, cyber security, and big data analytics applied to different areas.

Yixin Diao received the PhD degree in electrical engineering from Ohio State University, Columbus, OH, USA. He is currently a Director of Data Science and Analytics at PebblePost, New York, NY, USA. Prior to that, he was a Research Staff Member at IBM T. J. Watson Research Center, Yorktown Heights, NY, USA. He has published more than 80 papers and filed over 50 patents in systems and services management. He is the co-author of the book “Feedback Control of Computing Systems” and the co-editor of the book “Maximizing Management

Performance and Quality with Service Analytics.” He was a recipient of several Best Paper Awards from the IEEE/IFIP Network Operations and Management Symposium, the IFAC Engineering Applications of Artificial Intelligence, and the IEEE International Conference on Services Computing. He served as Program Co-chair for the International Conference on Network and Service Management in 2010, the IFIP/IEEE International Symposium on Integrated Network Management in 2013, and the IEEE International Conference on Cloud and Autonomic Computing in 2016 and served as General Co-chair for the International Conference on Network and Service Management in 2019. He is an Associate Editor of the IEEE Transactions on Network and Service Management and the Journal of Network and Systems Management. He is a Fellow of IEEE.

List of Contributors

Ahmad Alnafessah

Department of Computing
Imperial College London
London, UK

Kiril Antevski

Telematics Engineering Department
Universidad Carlos III de Madrid
Madrid, Spain

Remi Badonnel

Université de Lorraine
CNRS
Loria, Inria, Nancy, France

Jorge Baranda

Communication Networks Division
Centre Tecnològic de Telecomunicacions Catalunya
(CTTC/CERCA)
Barcelona, Spain

Sokratis Barmounakis

National and Kapodistrian University of Athens
Software Centric & Autonomic Networking lab
Athens, Greece

Carlos J. Bernardos

Telematics Engineering Department

Universidad Carlos III de Madrid

Madrid, Spain

Andreas Blenk

Chair of Communication Networks Department of
Electrical and Computer Engineering

Technical University of Munich

Munich, Germany

and

Faculty of Computer Science

University of Vienna

Vienna, Austria

Raouf Boutaba

David R. Cheriton School of Computer Science

University of Waterloo

Waterloo, Ontario, Canada

Valeria Cardellini

Department of Civil Engineering and Computer Science
Engineering

University of Rome Tor Vergata

Rome, Italy

Giuliano Casale

Department of Computing

Imperial College London

London, UK

Claudio Ettore Casetti

Department of Electronics and Telecommunications

Politecnico di Torino

Torino, Italy

Kai Chen

Department of Computer Science and Engineering, iSING
Lab

Hong Kong University of Science and Technology

Hong Kong SAR, China

Li Chen

Department of Computer Science and Engineering, iSING
Lab

Hong Kong University of Science and Technology

Hong Kong SAR, China

Carla Fabiana Chiasserini

Department of Electronics and Telecommunications

Politecnico di Torino

Torino, Italy

Koen De Schepper

Nokia Bell Labs

Antwerp, Belgium

Filip De Turck

Department of Information Technology

Ghent University - imec, IDLab Ghent, Technologiepark-
Zwijnaarde

Oost-vlaanderen, Belgium

Danny De Vleeschauwer

Nokia Bell Labs

Antwerp, Belgium

Yixin Diao

PebblePost

New York, NY, USA

Idilio Drago

University of Turin

Torino, Italy

Thomas Favale

Politecnico di Torino

Torino, Italy

Marija Gajić

Department of Information Security and Communication
Technology

Norwegian University of Science and Technology

Trondheim, Norway

Andrés García-Saavedra

NEC Laboratories Europe

5G Networks R&D Group

Heidelberg, Germany

Danilo Giordano

Politecnico di Torino

Torino, Italy

Carlos Guimarães

Telematics Engineering Department

Universidad Carlos III de Madrid

Madrid, Spain

Zied B. Houdi

Huawei Technologies
Boulogne-Billancourt
France

Patrick Kalmbach

Chair of Communication Networks
Department of Electrical and Computer Engineering
Technical University of Munich
Munich, Germany

Arjun Kaushik

Department of Electrical Engineering and Computer
Science
York University
Toronto, Ontario, Canada

Panagiotis Kontopoulos

National and Kapodistrian University of Athens
Software Centric & Autonomic Networking lab
Athens, Greece

Nikolaos Koursioupas

National and Kapodistrian University of Athens
Software Centric & Autonomic Networking lab
Athens, Greece

Frank A. Kraemer

Department of Information Security and Communication
Technology
Norwegian University of Science and Technology

Trondheim, Norway

Abdelkader Lahmadi

Université de Lorraine

CNRS

Loria, Inria, Nancy, France

Stanislav Lange

Department of Information Security and Communication
Technology

Norwegian University of Science and Technology

Trondheim, Norway

Xi Li

NEC Laboratories Europe

5G Networks R&D Group

Heidelberg, Germany

Xudong Liao

Department of Computer Science and Engineering, iSING
Lab

Hong Kong University of Science and Technology

Hong Kong SAR, China

Noura Limam

David R. Cheriton School of Computer Science

University of Waterloo

Waterloo, Ontario, Canada

Justinas Lingys

Department of Computer Science and Engineering, iSING
Lab

Hong Kong University of Science and Technology
Hong Kong SAR, China

Lina Magoula

National and Kapodistrian University of Athens
Software Centric & Autonomic Networking lab
Athens, Greece

Josep Manges-Bafalluy

Communication Networks Division
Centre Tecnològic de Telecomunicacions Catalunya
(CTTC/CERCA)
Barcelona, Spain

Jorge Martín-Pérez

Telematics Engineering Department
Universidad Carlos III de Madrid
Madrid, Spain

Ricardo Martínez

Communication Networks Division
Centre Tecnològic de Telecomunicacions Catalunya
(CTTC/CERCA)
Barcelona, Spain

Sadeq B. Melhem

Department of Electrical Engineering and Computer
Science
York University
Toronto, Ontario, Canada

Marco Mellia

Department of Electronics and Telecommunications
Politecnico di Torino
Torino, Italy

Stephan Merz

Université de Lorraine
CNRS

Loria, Inria, Nancy, France

Uyen T. Nguyen

Department of Electrical Engineering and Computer
Science

York University

Toronto, Ontario, Canada

Sina R. Niya

Communication Systems Group CSG

Department of Informatics IfI

University of Zürich UZH

Zürich, Switzerland

Chrysa Papagianni

Nokia Bell Labs

Antwerp, Belgium

Francesco Paolucci

Scuola Superiore Sant'Anna

Istituto TeCIP

Pisa, Italy

Francesco L. Presti

Department of Civil Engineering and Computer Science
Engineering

University of Rome Tor Vergata

Rome, Italy

Corrado Puligheddu

Department of Electronics and Telecommunications

Politecnico di Torino

Torino, Italy

Gabriele R. Russo

Department of Civil Engineering and Computer Science
Engineering

University of Rome Tor Vergata

Rome, Italy

Mohammad A. Salahuddin

David R. Cheriton School of Computer Science

University of Waterloo

Waterloo, Ontario, Canada

José Santos

Department of Information Technology

Ghent University - imec, IDLab

Ghent, Technologiepark-Zwijnaarde

Oost-vlaanderen, Belgium

Eryk Schiller

Communication Systems Group CSG

Department of Informatics IfI

University of Zürich UZH