Edited by
Emmanuel Bertin • Noel Crespi • Thomas Magedanz

Shaping Future 6G Networks

Needs, Impacts, and Technologies

IEEE PRESS
WILEY

Table of Contents

List of Tables

List of Illustrations

Shaping Future 6G Networks

Needs, Impacts, and Technologies

Edited by

Emmanuel Bertin
Orange Innovation/Institut Mines-Telecom

Noel Crespi
IMT, Telecom SudParis, Institut Polytechnique de Paris

Thomas Magedanz
Technische Universität Berlin/Fraunhofer FOKUS

IEEE PRESS

WILEY

This edition first published 2022

Registered Offices
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd., The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication Data Applied for

ISBN: 9781119765516

Cover Design: Wiley
Cover Image: © sutadimages/Shutterstock

Editor Biographies

Emmanuel Bertin (PhD) is a Senior Expert at Orange Innovation, France and an Adjunct Professor at Institut Polytechnique de Paris, France. His activities are focused on 5G and 6G, NFV and service engineering, with more than 100 published researched articles. He received a Ph.D. and an Habilitation in computer science from Sorbonne University. He is a senior member of the IEEE.

Noel Crespi(PhD) holds Masters degrees from the Universities of Orsay (Paris 11) and Kent (UK), a diplome d'ingénieur from Telecom Paris, and a Ph.D and an Habilitation from Sorbonne University. From 1993 he worked at CLIP, Bouygues Telecom and then at Orange Labs in 1995. He took leading roles in the creation of new services with the successful conception and launch of Orange prepaid service, and in standardization (from rapporteurship of the IN standard to the coordination of all mobile standards activities for Orange). In 1999, he joined Nortel Networks as telephony program manager, architecting core network products for the EMEA region. He joined Institut Mines-Telecom, Telecom SudParis in 2002 and is currently Professor and Program Director at Institut Polytechnique de Paris, leading the Data Intelligence and Communication Engineering Lab. He coordinates the standardization activities for Institut Mines-Telecom at ITU-T and ETSI. He is also an adjunct professor at KAIST (South Korea), a guest researcher at the University of Goettingen (Germany) and an affiliate professor at Concordia University (Canada). He is the scientific director of ILLUMINE, a French-Korean laboratory. His current research interests are in

Softwarization, Artificial Intelligence and Internet of Things. For more details: http://noelcrespi.wp.tem-tsp.eu/

Thomas Magedanz (PhD) has been Professor at the Technische Universität Berlin, Germany, leading the chair for next generation networks (www.av.tu-berlin.de) since 2004. In addition, since 2003 he has been Director of the Business Unit Software-based Networks (NGNI) at the Fraunhofer Institute for Open Communication Systems FOKUS (https://www.fokus.fraunhofer.de/usr/magedanz) in Berlin.

For 30 years Prof. Magedanz has been a globally recognized ICT expert, working in the convergence field of telecommunications, Internet and information technologies understanding both the technology domains and the international market demands. He often acts as an independent technology consultant for international ICT companies. In the course of his applied research and development activities he created many internationally recognized prototype implementations of global telecommunications standards that provide the foundations for the efficient development of various open technology testbeds around the globe. His interest is in software-based 5G networks for different verticals, with a strong focus on public and non-public campus networks. The Fraunhofer 5G Playground (www.5G-Playground.org) represents, in this regard, the world´s most advanced Open 5G testbed which is based on the Open5GCore software toolkit (www.open5Gcore.org), representing the first reference implementation of the 3GPP 5G standalone architecture, which is currently also used by many customers for testing against different RAN equipment in different use cases. For three years, he has actively supported the buildup of emerging 5G campus networks based on the Open5GCore considering emerging campus networks as the prime spot for 5G innovation.

His current research is targeting the 5G evolution to 6G, including Core-RAN integration (including O(pen)RAN integration), Satellite/Non-terrestrial Networks and 5G/6G integration, as well as AI/ML based 5G/6G network control and management.

For more details and a longer version look here:

http://www.av.tu-berlin.de/menue/team/prof_dr_thomas_magedanz/

List of Contributors

Zwi Altman
Orange Innovation
Châtillon
France

Alexis I. Aravanis
CNRS, Centrale
Supelec, L2S
University of Paris-Saclay
Gif-sur- Yvette
France

Joanna Balcerzak
Orange Innovation
Châtillon
France

Yosra Ben Slimen
Orange Innovation
Châtillon
France

Emmanuel Bertin
Orange Innovation
Caen
France

Nikolaus Binder
NVIDIABerlin
Germany

Holger Boche
Institute of Theoretical Information Technology
Technische Universität München

Munich
Germany

Mohamed Boucadair
Orange Innovation
Cesson-Sévigné
France

Juan A. Cabrera
Deutsche Telekom Chair of Communication Networks
Technische Universität Dresden
Dresden
Germany

Renato L.G. Cavalcante
TU Berlin/Heinrich Hertz Institute
Berlin
Germany

Marius Corici
Fraunhofer FOKUS
Berlin
Germany

Noel Crespi
IMT, Telecom Sud
Paris
Institut Polytechnique de Paris
Paris
France

Isabelle Dabadie
Laboratoire de recherche en sciences de gestion Panthéon-Assas (LARGEPA)
Université Paris 2 Panthéon-Assas
Paris France

Christian Deppe
Chair of Communication Engineering
Technische Universität München

Munich
Germany

Marco Di Renzo
CNRS, Centrale
Supelec, L2SUniversity of Paris-Saclay
Gif-sur- Yvette
France

Frank H. P. Fitzek
Deutsche Telekom Chair of Communication Networks.
Technische Universität Dresden
Dresden
Germany

Marco Giordani
Department of Information Engineering University of
Padova
Padova
Italy

Imen Grida Ben Yahia
Orange Innovation
Châtillon
France

Thomas Heyn
Head of Mobile Communications Group Broadband and
Broadcast Department
Fraunhofer IIS Erlangen
Germany

Alexander Hofmann
Department RF Sat
Com Systems Fraunhofer Institute for Integrated Circuits
Erlangen
Germany

Jinri Huang
China Mobile Research Institute

Beijing
China

Chih-Lin I
China Mobile Research Institute
Beijing
China

Christian Jacquenet
Orange Innovation
Cesson-Sévigné
France

Alexander Keller
NVIDIA Berlin
Germany

Markus Landmann
Electronic Measurements and Signal Processing (EMS) Department
Fraunhofer Institute for Integrated Circuits IIS. Ilmenau
Germany

Andres Laya
Ericsson Research
Stockholm
Sweden

Thomas Magedanz
Fraunhofer FOKUS
Berlin
Germany

Marie-José Montpetit
Montreal
Canada

Robert Müller
Electronic Measurements and Signal Processing (EMS) Department

Fraunhofer Institute for Integrated Circuits IIS. Ilmenau
Germany
Concordia University

Akihiro Nakao
The University of Tokyo
Tokyo
Japan

Zhisheng Niu
Tsinghua University
Beijing
China

Michele Polese
Institute for the Wireless Internet of Things
Northeastern University
Boston
MA
USA

Sahana Raghunandan
Department RF Sat
Com Systems Fraunhofer Institute for Integrated Circuits
Erlangen
Germany

Leszek Raschkowski
Wireless Communications and Networks Department
Fraunhofer Heinrich Hertz Institute HHI Berlin
Germany

Guy Redmill
Redmill Communications Ltd
London
UK

Rafael F. Schaefer
Chair of Communications Engineering and Security
University of Siegen

Siegen
Germany

Christian Scheunert
Chair of Communication Theory
Technische Universität Dresden
Dresden
Germany

Henning Schulzrinne
Columbia Univeristy
New York
USA

Sławomir Stańczak
TU Berlin/Heinrich Hertz Institute
Berlin
Germany

Peter Stuckmann
European Commision
Brussels
Belgium

Soma Velayutham
NVIDIA
Santa Clara
CA
USA

Marc Vautier
Orange Innovation
Cesson-Sévigné
France

David Zhe Lou
Huawei Technologies Düsseldorf GmbH
Munich
Germany

Sheng Zhou
Tsinghua University
Beijing
China

Michele Zorzi
Department of Information Engineering, University of Padova
Padova
Italy

Forewords

Henning Schulzrinne, Columbia University, USA

The first few iterations of cellular networks, 1G through 3G, were largely telephone networks with mobility added on, including the choice of addressing through telephone numbers, signaling through SS7, and emphasis on interoperable voice services. 4G and 5G started the transition to an Internet-driven architecture, with remnants of the old architecture still clearly visible. But beyond the protocol choices, all existing generations were largely driven by the assumption that networks are operated by a relatively small number of carriers, typically with at least a nationwide service footprint, reliant on licensed spectrum and an assumption of mutual trust. 5G has started to focus more attention on using the same radio technology for both industrial and consumer networks, but the large-carrier mindset still pervades the design, with a tightly-coupled set of protocols and entities. This tightly-coupled model provides some advantages; it bundles a consistent set of features and technologies designed and packaged to work together, relying on a strict user management and authentication framework. However, this model comes also with drawbacks, such as the lack of flexibility to adapt to new technologies or use-cases, and having to rely on three or at most four carriers in most countries.

Since 3G, branding mobile network generations have had both a technical and a consumer marketing role. The generations provided checkpoints for equipment vendors, and made advances in technology that's otherwise largely invisible to consumers relevant and marketable. 5G is probably the first iteration where a transition in technology standards became a matter of national pride and an indicator of national or regional competitiveness, with promises of increases in consumer and societal welfare that may be hard to deliver. However, as the digital divide during COVID-19 illustrated, universal access to affordable broadband, typically at home, mattered more than higher 5G speeds in the downtown business districts and digital transformation is not assured by having nationwide 5G. Thus, technologists and policy makers working on post-5G efforts should be careful in calibrating expectations, given that wireless network technology may not be the most significant hurdle that prevent addressing key societal challenges.

It seems likely that we will see a much larger variety of operational scenarios in the next decade, from traditional vertical-integrated carriers to disaggregated carriers and to private or federated enterprise networks. Any future network architecture needs to be sufficiently modular so that it can scale down to unmanaged home networks and scale up to networks where participants have limited trust in each other. This suggests a much more flexible and much simpler authentication and roaming model than we have had in previous network generations. Here, 6G can probably learn from another wireless technology where “generations” have played less of a role – ubiquitous Wi-Fi.

Developments for IoT during the 5G standardization and deployment phase may also hold lessons that encourage predictive modesty for 6G. Rather than being the universal network that connects billions and billions of IoT devices to create “smart” buildings and cities, cheap home Wi-Fi and new low-cost technologies like LoRa, leveraging unlicensed spectrum, have come to dominate, with carrier IoT offerings falling short of expectations – indeed, retaining boring and obsolete 2G often seems to draw more interest than new 5G ultralow latency capabilities.

Previous generations of cellular networks offered their per-user speed as the headline advantage, but 5G is already showing the limitations of that approach, as few mobile applications are likely to be built that will rely on 1 Gb/s or above speeds. Thus, the key metrics will not be per-user throughput or latency, but cost per base station month, governing deployment cost in low-density areas, and cost per bit delivered, i.e., primarily operational costs. Environmental metrics such as energy consumption or electromagnetic fields (EMF) must also be considered. For many years, capital equipment has only accounted for about 15% of revenues of most carriers, i.e., the vast majority of expenses are operational. This argues for a simple, self-managed, and robust network, with as many commodity components and protocols as possible and as much re-use of available fiber access networks as possible, rather than infinite configurability or elaborate QoS mechanisms. The largest opportunities for improved operational efficiency and reduced complexity are in the control plane, not the data plane, relying for that on machine learning and automation technologies as detailed in this book. However, since 6G will serve as infrastructure, with concomitant reliability expectations, robustness, predictability and explainability of any use of machine learning will be more important than squeezing out the last percentage points of efficiency.

Despite all the changes in technology, the common thread across mobile technology generations has been a dramatic reduction in the consumer unit cost of mobile data, with new applications enabled simply because they became affordable. Thus, 6G will likely only offer a significant value proposition beyond a marketing tag line if it is engineered to minimize operational complexity, maximizes operational automation and ensures high availability. The Wi-Fi experience can offer lessons and might even offer an