Integration of MTC and Satellites for IoT toward 6G era

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IEEE Press

with website

WILEY

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IEEE Press
445 Hoes Lane
Piscataway, NJ 08854

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

Library of Congress Cataloging-in-Publication Data

Names: Alves, Hirley, editor. | Mikhaylov, Konstantin, editor. | Hoyhtya, Marko, editor.
Title: Integration of MTC and satellites for IoT toward 6G era / edited by Hirley Alves, University of Oulu, Konstantin Mikhaylov, Marko Hoyhtya.
Description: Hoboken, New Jersey : Wiley, [2023] | Includes bibliographical references and index.
Identifiers: LCCN 2024009003 (print) | LCCN 2024009004 (ebook) | ISBN 9781119933977 (hardback) | ISBN 9781119933984 (adobe pdf)
Subjects: LCSH: 6G mobile communication systems. | Artificial satellites in telecommunication. | Internet of things.
Classification: LCC TK5103.252 .I58 2023 (print) | LCC TK5103.252 (ebook) | DDC 621.3845/6–dc23/eng/20240319
LC record available at https://lccn.loc.gov/2024009003
LC ebook record available at https://lccn.loc.gov/2024009004

Cover Design: Wiley
Cover Image: © desmon jiag/Getty Images

Set in 9.5/12.5pt STIXTwoText by Straive, Chennai, India

To our families.

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Preface

The IoT concept emerged in the 2000s and increased during the last decade. Currently, we are experiencing the deployment of the first IoT applications on a large scale. We foresee that this trend will continue in the coming years. However, much more development and research are needed to cope with the forecasted billions of interconnected devices merged into the Internet in the next decade. Due to the massiveness of the network, current wireless technologies (e.g. LoRaWAN, Cellular-IoT, ZigBee, WiFi, BLE) need to be revised to attend to such demand, even more so concerning energy efficiency and network scalability. This challenge is especially crucial for areas with low population and infrastructure density. Remember that oceans cover a significant share of the Earth's surface, where static infrastructure deployment is exceptionally challenging. Even though it is reasonable to expect lower IoT device density in these regions than in urban environments, where connectivity is well established today, many new applications and services must be deployed in the future to tackle sustainable development goals.

The idea of interconnecting mobile and satellite networks gained much interest from both industry and academia during the past decade, particularly in the cases of coverage extension and backhauling in remote areas. The work has focused chiefly on complementing terrestrial services. This idea has been recently renewed and expanded for seamless IoT integration of mobile and satellite networks. A notable example is directly connecting IoT devices through satellites (direct-to-satellite (DtS)). In addition, the industry (e.g. Iridium, Sateliot, OneWeb, Lacuna Space, and Starlink, to name a few) is continually developing new services to support IoT. Simultaneously, the work on standardization (such as the work actively ongoing within the 3GPP and LoRa alliance) of the DtS is now emerging. Some visions suggest that DtS will become integral to the 6th generation (6G) mobile systems. However, given the novelty of the targeted field and the challenging requirements (e.g. the unprecedented mobility of the low Earth orbit (LEO) satellites, the colossal communication link distances, and the lack of possibility of servicing the satellites after launch), the integration of IoT and satellite, especially in the context of DtS approach, imposes development of new architectures and technical solutions. Simultaneously, the IoT devices' requirements and traffic patterns differ from conventional satellite terminals today. Another substantial challenge that hampers innovation is the need for more experts in this novel field and relevant textbooks to educate such experts.

This book addresses this challenge by discussing the integration of machine-type communications (MTC) and satellite communication toward 6G. The MTC term emerged during 5G standardization but has grown beyond its original scope. MTC encompasses all (wireless) connectivity solutions and technologies for IoT, including non-cellular ones, e.g. Low-Power Wide Area (LPWA). This book analyzes the drivers, use cases, scenarios, requirements, and architectures of such systems. Besides, we cover the challenges from physical (PHY) to application layers within the detailed and self-sustainable technical chapters. Notably, we review analytical, emulation, and end-to-end simulation tools suitable for the analysis and design of satellite systems. Moreover, we also discuss MTC and satellite integration from the standardization, regulation, and spectrum management points of view. Finally, we analyze and propose new business models and businesses from MTC and satellite integration.

We aim to make the book relevant to students obtaining their first professional degree and the experts who operate in this or adjacent fields and want to revise and update their knowledge or consider changing their focus to this new, promising, and exciting area.

Oulu *Hirley Alves, Konstantin Mikhaylov, and Marko Höyhtyä*
14 March 2023

Acknowledgments

We thank our colleagues and collaborators for helpful discussions and support in developing this book. We thank our students and colleagues for promptly assisting with insightful and timely reviews. In addition, the book's preparation received support from Business Finland through the 6G-SatMTC project and the Research Council of Finland through 6G Flagship program (grant 346208) and MRAT-SafeDrone project (grant 341111).

We want to thank the authors from the academy and industry for their valuable and insightful contributions and support despite their busy schedules. Their expertise, covering both state-of-the-art industrial knowledge and the latest research advancements done at universities and research institutes, helped make this book a helpful tool for students, researchers, and practitioners to integrate machine-type communication and satellite networks.

Acronyms

3D	Three-Dimensional
3GPP	3rd Generation Partnership Project
4G	Fourth Generation of Broadband Cellular Network Technology
5G	Fifth Generation Standard for Broadband Cellular Networks
5GC	5G Core Network
5GNR	Fifth-Generation New Radio
6G	Sixth Generation of Cellular Networks
6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks
ACM	Adaptive Coding and Modulation
ADR	Adaptive Data Rate
AFC	Automated Frequency Coordination
AH	Authentication Header
AI	Artificial Intelligence
AirComp	Over-the-Air Computation
AKA	Authentication and Key Management
AMF	Access and Mobility Function
AMQP	Advanced Message Queuing Protocol
ANR	Automatic Neighbor Relations
AODV	Ad Hoc On-Demand Distance Vector
API	Application Programming Interface
ARP	Address Resolution Protocol
ARPU	Average Revenue Per User
ARQ	Automatic Repeat Request
ASTOS	Analysis Simulation and Trajectory Optimization Software
AWGN	Additive White Gaussian Noise
B2B	Business to Business
BER	Bit Error Rate
BGP	Border Gateway Protocol
BLE	Bluetooth Low Energy

BP	Bundle Protocol
bps	Bits Per Second
BSS	Broadcast Satellite Service
BTP	Basic Transport Protocol
BW	Bandwidth
C-V2X	Cellular Vehicle-to-Everything
CAGR	Compound Annual Growth Rate
CAM	Cooperative Awareness Message
CAT	Category
CBR	Constant Bit Rate
CCSDS	Consultative Committee for Space Data Systems
CFO	Carrier Frequency Offset
CFS	Contention-Free Shared
CGC	Complementary Ground Component
CHO	Conditional HO
CINR	Carrier-to-Interference-Plus-Noise Ratio
CIoT	Cellular Internet-of-Things
CIR	Carrier-to-Interference Ratio
CL	Clutter Loss
cMTC	Critical MTC
CN	Core Network
CNFs	Cloud-Native Network Functions
CNN	Convolutional Neural Network
CNR	Carrier-to-Noise Ratio
Co-IoT	Collaborative Internet-of-Things
CoAP	Constrained Application Protocol
ComSec	Communication Security
COTS	Commercial Off-the-Shelf
CP	Cyclic Prefix
CPU	Central Processing Unit
CR	Cognitive Radio
CRDSA	Contention Resolution Diversity Slotted Aloha
CS	Circuit Switched
CSA	Coded Slotted ALOHA
CSMA	Carrier Sense Multiple Access
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSOC	Cybersecurity Operations Centers
CSS	Chirp Spread Spectrum
CU	Centralized Unit
D2D	Device-to-Device
DAMA	Demand Assignment Multiple Access