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6G: Sustainable Development for Rural and Remote Communities

Springer

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Foreword I

The book covers a variety of feasible technology options, both wired and wireless, to enable 6G connectivity in rural and remote regions. Along with the enabling technology options, the book also covers important aspects such as human–computer interaction, business models for the local operator ecosystem, regulatory and right-of-way policies, security and privacy, and future challenges related to technology migration, urbanization, and scalability. A special feature of this book is that it covers both the optical and wireless technology aspects to realize 6G connectivity, which will be interesting to a broad range of researchers and practitioners. This book covers all such technical and non-technical aspects that will be of interest to researchers, decision-makers, academia, social workers, and the casual readers interested in technology/growth/empowerment. Further, the simple explanations, pictorial representations, minimal math, and conversational language will enable all the readers to grasp it, thereby helping them in decision-making and performing comprehensive analysis, which will ultimately benefit themselves and society.

In summary, this book is a very interesting read for all, as it explains the technological advances in simple language for the non-expert in the field. It covers advances and challenges across the world in connecting the unconnected using 6G. The book also covers and compares the current connectivity issues in various Indian states including the outcomes of the authors' visit to rural Madhya Pradesh and the North Eastern region of India. Many potential solutions for policymakers and engineers for improving connectivity and usability with business and entrepreneurship-driven models are covered for both India and Finland. This is very interesting collaborative research by the Indian and Finnish research groups with high impact for upliftment of rural and remote communities of both countries and the world. I congratulate the authors for writing this futuristic book and recommend it to all to read.

05 March 2022

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Foreword II

Mobile technologies have dramatically changed societies worldwide and have become essential parts of critical infrastructure. The first two generations brought voice connectivity to our pockets, and 3rd and 4th generation mobile internet connectivity. Now, with 5G and next with 6G, the pervasive digitalization of societies will dramatically change our daily routines. This development has taken place mainly due to the interests of developed economies. Most recently, 5G standard development has been driven by improving the economic efficiency of such countries. At the same time, increasing concerns about sustainable development worldwide are gaining more space in governments' technology agendas. Sustainability involves all segments of society, and technological innovations have a crucial role in solving many burning problems.

Wireless technologies are in a key position in most of the seventeen United Nations Sustainability Development Goals (UN SDGs). The global community has widely accepted UN SDGs to the center of 6G development. So far, only technical requirements via several Key Performance Indicators (KPIs) have been addressed when developing mobile cellular systems for the future. Key Value Indicators (KVIs) are also being defined for the global 6G standards development under several major 6G research programs, particularly those operating within Europe. It is fair to say that the change in attitudes is taking place now, and 6G can be expected to better answer the needs of SDGs.

Remote areas connectivity solutions are in a vital position when developing 6G. The future of digital societies depends on always-on connectivity. The quality of life in developing regions can be drastically improved via reasonable and affordable solutions matching the local needs. More robust solutions for providing electricity to maintain networks and provisioning backhaul solutions are needed. New ways of thinking maybe necessary for service provisioning—what does the quality of service mean in remote sparsely populated areas compared to metropolitan areas? Besides novel technical solutions, innovative thinking is required in economics, politics, and regulation.

The challenges mentioned above have been studied in collaboration with the 6G Flagship Program at the University of Oulu and a SPARC funded project within

IIT Indore. The project team has captured some of the key challenges by going through connectivity coverage, user challenges, and developments across the world with detailed case studies in diverse topography of India. However, this is only the beginning of a longer journey deserving more research efforts in the future. I hope this book inspires both the R&D community and decision-makers to better understand and solve the urgent needs for sustainable development for a better future!

05 March 2022

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Preface

5G brings enhanced quality of service (QoS) to the existing users via the technologies providing higher capacity, lower latency, higher reliability, massive connectivity, among others. However, the fact that about half of the global population has no access to the Internet at present has not been considered during the 5G research and development (R&D) and standardization, and hence it has missed on bridging the global digital divide. With the arrival of 5G, the digital divide will broaden further since the focus of 5G R&D has been on improving the existing users' experience, to provide advanced services, and to increase the network operators' revenues. As the research on beyond 5G (B5G)/6G communication networks is gaining momentum all over the world, it is necessary to focus on the aspects of connecting the unconnected, bridging the digital divide, and global digital inclusion from the very beginning. As part of the 2030 agenda for United Nations Sustainable Development Goals (UN SDGs), 'access to Internet as a basic human right around the world' has been projected as one of the most promising solutions to help achieve these goals. Moreover, it has also been mentioned (and widely accepted) that these goals cannot be achieved without affordable access to Internet by everyone, everywhere. Thus, the focus of B5G/6G research should also be on developing solutions to provide affordable access to Internet to the unconnected population, a majority of which resides in the rural and remote regions of the lower- and middle-income countries.

This book provides an overview of the present state of Internet connectivity in different parts of the world, the main reasons behind the current digital divide, important factors to be considered to connect the unconnected and under-connected, various technological options and architectures that can be deployed in the rural and remote regions, techno-economic aspects and local micro-operator ecosystem, human–computer interaction (HCI), and the future challenges to ensure sustainable development of rural regions, and to prevent the digital divide from broadening further.

As observed during and after the development of 5G technologies, there has been confusion and debate over '5G Vs Fiber', and questions such as 'will 5G replace fiber?' what actually is 5G, and progression of softwarization for networking in general have been posed. However, in the telecommunications infrastructure, the

fiber optics and wireless technologies complement each other. Fiber optics enable the Internet, act as a substrate for the telecom-cloud infrastructure, and form the backbone of long-distance communication, wherein the traffic from the wireless metro/access network aggregates. On the other hand, wireless technology enables last-mile mobile connectivity and is responsible for defining the end-user QoS and quality of experience (QoE). Thus, fiber optics and wireless (no matter whether it is 2G/3G/4G/5G/6G) have coexisted and complemented each other, and will continue to coexist in the future. This book covers both the fiber optics as well as wireless technology aspects to realize 5G and B5G connectivity.

The regional demographics play a significant role in defining the telecommunication network coverage and the QoS. Moreover, it is necessary to consider the existing information and communication technology (ICT) infrastructure, and the ongoing projects to develop new technologies, methods, and business models for 5G/B5G connectivity in rural and remote areas. Chapter 1 of this book provides an overview of the broadband infrastructure in different parts of the world including India, Finland, Japan, Africa, Americas, among others. Interesting observations are drawn based on the existing wireless and wired network infrastructure in different countries, and the corresponding performance and QoS of the broadband services in such regions. Emphasis has been laid on the ongoing projects in different countries, region-specific needs, and the diverse challenges that need to be addressed to connect the unconnected rural and remote regions in different parts of the world.

Chapter 2 focuses on key considerations to achieve affordable B5G/6G connectivity in rural regions from both the operators' and users' perspective. Various challenges to be addressed in the new B5G micro-operator ecosystem to be developed in rural regions are identified. Specifically, power issues, ease-of-use, security, resilience, risk, scalability, and other factors that are crucial for sustainable connectivity in rural regions are described. Special focus has been laid on the need of renewable sources of energy to support the power requirements of the ICT infrastructure to be deployed in the rural and remote regions, where power grids are either not deployed or have limited availability.

Chapter 3 describes several promising wireless and fiber optics technology options to connect the unconnected from the view of rural and remote regions' suitability. In different parts of the world, the presence of fiber optics is different. Moreover, it has been observed that in some regions, the existing and the ongoing fiber-optics deployment is either underutilized or cannot achieve the last-mile connectivity. The discussion on wireless technology options covers such possible scenarios in different parts of the world, where the advanced and affordable wireless options can achieve last-mile connectivity as well as act as wireless backhaul/fronthaul in the regions where fiber-optics networks are either non-existent or hard to be deployed, such as difficult terrains. Special emphasis has been laid on leveraging the existing telecommunications infrastructure in India, and alignment with the ongoing projects, such as BharatNet and others, to realize affordable wireless Internet in the rural regions of India. Moreover, technology options for innovative HCI are elucidated considering the illiterate and digitally disadvantaged rural population with a view to maximize

the use of devices and service consumption. Security and privacy aspects considering the rural population are also emphasized.

While there are different possible ways to connect the unconnected regions, and most of the technology is available currently, as discussed in Chap. 3, the main challenge is to customize and optimize at the systems level to realize affordable 5G/B5G connectivity. Chapter 4 describes various systems architectures to connect the unconnected regions, to improve the connectivity in the under-connected regions, and to provide affordable access to the Internet in the rural regions. Furthermore, the major global initiatives to improve rural and remote connectivity are discussed.

In Chap. 5, the techno-economic challenges to reduce CAPEX and OPEX to achieve affordable 6G connectivity in rural and remote regions are discussed. Economic estimates for future communication technologies are also discussed, which will play a crucial role in cost-efficient network planning considering the possible modifications in the future networks. The concept of micro-operator ecosystem is described along with the aspects of sustainability and profitability for rural micro-operator ecosystem involving village-level entrepreneurs. Issues related to licensing and permissions are also described for timely deployment of network solutions.

The quality of service as well as the diverse service requirements have been evolving with every new generation of communications. Factors such as development of new network applications, gadgets, urbanization, technology migration, socio-cultural aspects, and the expected conversion of users from freemium to premium in future necessitates the consideration of future technical challenges to address the aspects such as those related to scalability, sustainability, upgradation, and demand forecasting. Once the unconnected regions are connected, it will be another challenge to prevent the digital divide from broadening further and match the pace of progress in rural regions with that of the urban regions. Chapter 6 describes all the above-mentioned aspects, future technologies, and the importance of technology migration.

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March 2022

Contents

1 Digital Divide and Its Current State 1
1.1 India 5
1.1.1 Current State 8
1.1.2 Ongoing Projects 8
1.1.3 Future Aspects 9
1.2 The World 10
1.2.1 Current State 10
1.2.2 Ongoing Projects 12
1.2.3 Future Aspects 13
References 14

2 Key Considerations to Achieve 5G and B5G Connectivity in Rural Areas 17
2.1 Users' Perspective 17
2.1.1 Affordability 18
2.1.2 Ease-of-Use 18
2.1.3 Security 18
2.1.4 Services and Applications 19
2.2 Operators' Perspective 19
2.2.1 Power Issues 19
2.2.2 Interference 22
2.2.3 Maintenance 22
2.2.4 Resilience 22
2.2.5 Risk 22
2.2.6 Scalability 23
References 23

3 Technology Drivers for 6G 25
3.1 Wireless Technology 25
3.1.1 Multiple-Input Multiple-Output (MIMO) 25
3.1.2 TV White Space 26
3.1.3 mmWave 27

3.1.4 Beamforming 30
3.1.5 Spectrum Reframing 31
3.2 Fiber Optics 33
3.2.1 Leveraging the Deployed Optical Fiber Network 35
3.2.2 Exploiting the Power Distribution Network 38
3.3 Technologies for Human–Computer Interaction 40
3.3.1 Users in Rural Regions and the Associated Challenges 41
3.3.2 Touch and Display 43
3.3.3 Speech and Gesture-Based Inputs 43
3.3.4 HCI for People with Disability 44
3.3.5 HCI for Children 44
3.3.6 Consideration for Elderly Population 45
3.3.7 Summary 46
3.4 Security 47
3.4.1 Biometric Authentication 48
3.5 Data Storage 49
3.5.1 Cloud Storage 49
3.5.2 Edge Storage 51
References 53

4 Systems Architecture and Major Global Initiatives 59
4.1 Architecture for Connectivity in Rural Regions 59
4.1.1 Remote Regions with no Infrastructure 60
4.1.2 Regions with Limited Infrastructure 61
4.2 Architectures for Enabling Affordable Service Provisioning in Rural Regions 66
4.3 Global Initiatives for Rural and Remote Connectivity 69
4.3.1 6G Flagship 70
4.3.2 Basic Internet Foundation 70
4.3.3 Broadband Commission for Sustainable Development 71
4.3.4 IEEE International Network Generations Roadmap 71
4.3.5 Wireless World Research Forum 72
4.3.6 World Bank Digital Development Initiative 72
4.3.7 Internet Society—Wireless for Communities 72
4.3.8 SMART Africa 73
4.3.9 Organization for Economic Co-Operation and Development 73
References 73

5 Techno-economic Challenges 75
5.1 Economic Estimates for Future Communication Technologies 75
5.1.1 Quantum Communication Technology 76
5.2 CAPEX 77
5.3 OPEX 78

5.4 Micro-operator Ecosystem 78
5.4.1 Sustainability 78
5.4.2 Profitability 80
5.5 Licenses and Permissions 80
References 80

6 Future Challenges 81
6.1 Differentiated Service 81
6.2 Demand Forecasting 82
6.2.1 Urbanization 82
6.2.2 First Responder Services 82
6.3 Technology Migration 83
6.3.1 Wireless 83
6.3.2 Fiber Optics 87
6.4 Haptic Technology 97
6.5 Socio-cultural Aspects 99
References 102

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Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
ACSR	Aluminum Conductor Steel-Reinforced
ADC	Analog to Digital Converter
AfDB	African Development Bank
AI	Artificial Intelligence
AP	Access Point
AWGN	Additive White Gaussian Noise
B5G	Beyond 5G
BBNL	Bharat Broadband Network Limited
BFSI	Banking Financial Services and Insurance
BIF	Basic Internet Foundation
BON	Backbone Optical Network
bps	Bits Per Second
BS	Base Station
BSNL	Bharat Sanchar Nigam Limited
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
C-Band	Conventional Band
CCI	Child-Computer Interaction
CLS	Cable Landing Station
CoS	Class of Service
CR	Cognitive Radio
CSCL	Computer-Support for Collaborative Learning
CSR	Corporate Social Responsibility
CTU	Connecting the Unconnected
D2D	Device to Device
DAC	Digital to Analog Converter
DAM	Distance Adaptive Modulation
DC	Datacenter
DESI	Digital Economy and Society Index

DigI	Digital Inclusion
DNA	Deoxyribonucleic Acid
DoA	Direction of Arrival
DPG	Digital Public Goods
EAFRD	European Agricultural Fund for Rural Development
EEG	Electroencephalogram
EM	Electromagnetic
EON	Elastic Optical Network
EoT	Everything on Tower
EU	European Union
FCC	Federal Communications Commission
FD	Full-duplex
FD-CR	Full-duplex Cognitive Radio
FTTH	Fiber to the Home
GDP	Gross Domestic Product
GoF	Government of Finland
GoI	Government of India
GP	Gram Panchayat
GPON	Gigabit Passive Optical Network
GSMA	Global System for Mobile Communications Association
HAP	High-Altitude Platform
HAPS	High-Altitude Platform Station
HCI	Human–Computer Interaction
HD	Half-duplex
HD-CR	Half-duplex Cognitive Radio
HF	High Frequency
HP	Hewlett Packard
HSBNN	High Speed Broadband Network in the North
IAB	Integrated Access and Backhaul
ICANN	Internet Corporation for Assigned Names and Numbers
ICT	Information and Communication Technology
ICT4D	Information and Communication Technology for Development
IEEE	Institute of Electrical and Electronics Engineers
IIT	Indian Institute of Technology
INGR	International Network Generations Roadmap
IoH	Internet of Health
IoT	Internet of Things
IPTV	Internet Protocol Television
IRS	Intelligent Reflecting Surface
ITU	International Telecommunication Union
IVR	Interactive Voice Response
KPI	Key Performance Indicator
LEO	Low Earth Orbit
LTE	Long-Term Evolution

M2M	Machine to Machine
MAC	Medium Access Control
MCF	Multicore Fiber
mDC	Micro Datacenter
MeitY	Ministry of Electronics and Information Technology
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
MMF	Multimode Fiber
M-MIMO	Massive-MIMO
MNO	Mobile Network Operator
MoE	Ministry of Education
NBM	National Broadband Mission
NFAP	National Frequency Allocation Plan
NFV	Network Function Virtualization
NGA	Next Generation Access
NGO	Non-Governmental Organization
NG-PON	Next-Generation Passive Optical Network
NKN	National Knowledge Network
NLD	National Long-distance Provider
NOFN	National Optical Fiber Network
NOMA	Non-Orthogonal Multiple Access
OECD	Organization for Economic Co-operation and Development
OFC	Optical Fiber Cable
OLT	Optical Line Terminal
ONT	Optical Network Terminal
ONU	Optical Network Unit
OPEX	Operational Expenditure
OPGW	Optical Ground Wire
O-RAN	Open Radio Access Network
OSNR	Optical Signal to Noise Ratio
OTP	One Time Password
PDO	Public Data Office
PIN	Personal Identification Number
PM-WANI	Prime Minister Wi-Fi Access Network
PoI	Point of Interconnection
PON	Passive Optical Network
PoP	Point of Presence
PU	Primary User
QKD	Quantum Key Distribution
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RF	Radio Frequency

RoI	Return on Investment
RoW	Right of Way
RSS	Reconfigurable Smart Surface
RU	Radio Unit
SAARC	South Asian Association for Regional Cooperation
SBS	Small Base Station
SDG	Sustainable Development Goals
SDM	Space Division Multiplexing
SDN	Software Defined Networking
SINR	Signal to Interference and Noise Ratio
SL	Supervised Learning
SLA	Service Level Agreement
SNR	Signal to Noise Ratio
SP	Service Provider
SPARC	Scheme for Promotion of Academic and Research Collaboration
SS-FON	Spectrally-Spatially Flexible Optical Network
SSL	Semi-supervised Learning
SSMF	Standard Single-Mode Fiber
STL	Sterlite Technologies Limited
SU	Secondary User
TDM	Time Division Multiplexing
TRAI	Telecom Regulatory Authority of India
TRN	Trusted Repeater Node
TV	Television
TVWS	Television White Space
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UHF	Ultra-High Frequency
UI	User Interface
UK	United Kingdom
UL	Unsupervised Learning
UM-MIMO	Ultra-Massive-MIMO
UN	United Nations
UNESCO	United Nations Educational Scientific and Cultural Organization
URLLC	Ultra-Reliable Low-Latency Communication
USA	United States of America
VHetNet	Vertical Heterogeneous Network
VHF	Very High Frequency
VLE	Village Level Entrepreneur
VNF	Virtual Network Function
VNI	Visual Networking Index
VR	Virtual Reality
W4C	Wireless for Communities
WBAN	Wireless Body Area Network

WDM	Wavelength Division Multiplexing
WMD	Weapons of Mass Destruction
WRAN	Wireless Radio Access Network
WWRF	Wireless World Research Forum
XGS-PON	10 Gigabit Symmetrical Passive Optical Network

List of Figures

Fig. 1.1 Rural population and the population unconnected to the Internet in different countries [5, 6] 2
Fig. 1.2 Crucial aspects of rural connectivity 3
Fig. 1.3 Classification of global population to determine the technological challenges in connecting the unconnected 4
Fig. 1.4 Growth of Internet subscribers in India in the last five years 6
Fig. 2.1 Share of the population with access to electricity until 2019 [1, 2] 20
Fig. 2.2 Solar resource map indicating the photovoltaic power potential in different parts of the world [4] 20
Fig. 2.3 Wind resource map indicating the mean wind speed in different parts of the world [5] 21
Fig. 3.1 mmWave connectivity fabric [28] 28
Fig. 3.2 mmWave coverage in shared spectrum [28] 29
Fig. 3.3 Outdoor mmWave applications [31] 29
Fig. 3.4 Hybrid-beamforming transmitter–receiver architecture for UM-MIMO system 32
Fig. 3.5 Spectrum availability for mobile broadband and sections of spectrum unsuitable for information transfer 33
Fig. 3.6 ITU interactive transmission map [40] 33
Fig. 3.7 The predicted growth of global Internet traffic as per the Cisco Visual Networking Index (VNI) forecast 2017–2022 [42] 34
Fig. 3.8 Role of optical networks in a Telecom-Cloud Infrastructure [43] 35
Fig. 3.9 Concept diagram of rural connectivity under BharatNet [44] 36
Fig. 3.10 Musapuri village in the Bhagwanpura block of Khargone, Madhya Pradesh 37
Fig. 3.11 OFC deployed/proposed in the Bhagwanpura block under BharatNet [45] 37
Fig. 3.12 Duct laying and GPON installation under the BharatNet [48] 38

Fig. 3.13 Transmission lines installed in the hilly regions of **a** Jammu and Kashmir [49] and **b** North—East region of India 39
Fig. 3.14 Overhead OPGW installation in POWERTEL [50] 40
Fig. 3.15 An illustration of the power of multi-mode HCI on user experience. (Courtesy HP Labs India) 41
Fig. 3.16 People riding on bullock cart in Musapuri 42
Fig. 3.17 A representative kutcha house at Musapuri 42
Fig. 3.18 Cybercrime victims in different countries in 2019 [89] 47
Fig. 3.19 Top 5 countries affected by ransomware attacks in the Q3 of 2020 [90] 48
Fig. 3.20 Illustration of cloud storage in rural areas 50
Fig. 3.21 Illustration of an edge storage-enabled cellular network 52
Fig. 3.22 System model for device-to-device storage 52
Fig. 4.1 Most common backhaul options to provide connectivity in rural/remote regions: **a** Fiber backhaul, **b** Microwave backhaul, and **c** Satellite backhaul 60
Fig. 4.2 Technology options to connect remote regions with no infrastructure [1] 61
Fig. 4.3 Solution to extend coverage in the holes using small cells [1] 62
Fig. 4.4 Connecting the rural clustered establishments using beamforming [1] 63
Fig. 4.5 Basic concept of Frugal 5G [2] 63
Fig. 4.6 Architecture of Frugal 5G [2] 64
Fig. 4.7 The concept of EoT [3, 4] 65
Fig. 4.8 Bluetown's microwave backhaul mesh network [3, 4] 65
Fig. 4.9 Architecture for rural connectivity by C-DOT [5] 67
Fig. 4.10 Freemium model for access to heavy and lite bandwidth by rural consumers 68
Fig. 4.11 A holistic view of rural connectivity infrastructure with freemium service 68
Fig. 4.12 Popular regional content sharing during low congestion in a preemptive way 69
Fig. 5.1 Funding for quantum initiatives around the world [1] 76
Fig. 5.2 Market growth forecast for QKD systems [2] 77
Fig. 5.3 Micro-operator concept and ecosystem [3] 79
Fig. 6.1 **a** Interweave CR scenario and **b** Underlay CR scenario 83
Fig. 6.2 IRS system model [16] 85
Fig. 6.3 Various use-cases for the HAPS 86
Fig. 6.4 Factors necessitating the need of capacity enhancement of optical networks 87
Fig. 6.5 Increased capacity requirement in the B5G/6G era for submarine, terrestrial backbone, and middle/last-mile optical networks 89
Fig. 6.6 WDM fixed grid versus EON flexible grid 90
Fig. 6.7 Multicore fibers 90

Fig. 6.8 Difference between classical communication and QKD secured communication 92
Fig. 6.9 Quantum–classical coexistence in optical networks 94
Fig. 6.10 Seismic-risk aware optical network densification 95
Fig. 6.11 Infrastructure cost of primary and backup paths in optical networks [52] 96
Fig. 6.12 A representative mDC [40] 97
Fig. 6.13 Fog-computing enabled by high-capacity and low-latency optical networks interconnecting the mDCs 97