



ENABLING 5G COMMUNICATION SYSTEMS TO SUPPORT VERTICAL INDUSTRIES

EDITED BY

MUHAMMAD ALI IMRAN | YUSUF ABDULRAHMAN SAMBO
QAMMER H. ABBASI


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Edited by

Muhammad Ali Imran

University of Glasgow
UK

Yusuf Abdulrahman Sambo

University of Glasgow
UK

Qammer H. Abbasi

University of Glasgow
UK

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About the Editors

Muhammad Ali Imran is the Vice Dean Glasgow College UESTC and Professor of Communication Systems in the School of Engineering at the University of Glasgow. He leads the Communications, Sensing and Imaging research group. He was awarded his MSc (Distinction) and PhD degrees from Imperial College London, UK, in 2002 and 2007, respectively. He is an Affiliate Professor at the University of Oklahoma, USA and a visiting Professor at 5G Innovation Centre, University of Surrey, UK. He has over 18 years of combined academic and industry experience, working primarily in the research areas of cellular communication systems. He has been awarded 15 patents, has authored/co-authored over 300 journal and conference publications, and has been principal/co-principal investigator on over £6 million in sponsored research grants and contracts. He has supervised 30+ successful PhD graduates. He has an award of excellence in recognition of his academic achievements, conferred by the President of Pakistan. He was also awarded IEEE Comsoc's Fred Ellersick Award 2014, FEPS Learning and Teaching Award 2014, and Sentinel of Science Award 2016. He was twice nominated for Tony Jean's Inspirational Teaching Award. He is a shortlisted finalist for The Wharton-QS Stars Awards 2014, QS Stars Reimagine Education Award 2016 for innovative teaching and VC's learning and teaching award in University of Surrey. He is the co-editor of two books: *Access, Fronthaul and Backhaul Networks for 5G and Beyond*, published by IET, ISBN 9781785612138, and *Energy Management in Wireless Cellular and Ad-hoc Networks*, published by Springer, ISBN 9783319275666. He is a senior member of IEEE, Fellow of IET and a Senior Fellow of Higher Education Academy (SFHEA), UK.

Yusuf Abdulrahman Sambo received the MSc degree (Distinction) in Mobile and Satellite Communications, in 2011, and the PhD degree in electronic engineering in 2016, from the Institute for Communication Systems (ICS, formally known as CCSR) of the University of Surrey. He is currently a Postdoctoral Research Associate in the mobility, massive Internet Communications, Sensing and Imaging (CSI) research group at the University of Glasgow. Prior to joining the University of Glasgow, he was a Lecturer in Telecommunications Engineering at Baze University, Abuja from June 2016 to September 2017. His main research interests include self-organized networks, radio resource management, EM exposure reduction, energy efficiency and 5G testbed implementation. He is a member of IEEE and the IET. He has served as technical program committee member of several IEEE conferences and as reviewer for several IEEE and other top journals. He has also contributed in organizing IEEE conferences and workshops.

Qammer H. Abbasi received his BSc and MSc degrees in electronics and telecommunication engineering from University of Engineering and Technology (UET), Lahore, Pakistan (with Distinction). He received his Ph.D. degree in Electronic and Electrical engineering from Queen Mary University of London (QMUL), UK, in January, 2012. Until June 2012, he was Postdoctoral Research Assistant in Antenna and Electromagnetics group, QMUL, UK. From 2012 to 2013, he was international young scientist under National Science Foundation China (NSFC), and Assistant Professor in University of Engineering and Technology (UET), KSK, Lahore. From August, 2013 to April 2017 he was with the Centre for Remote Healthcare Technology and Wireless Research Group, Department of Electrical and Computer Engineering, Texas A&M University (TAMUQ), initially as an Assistant Research Scientist and later was promoted to an Associate Research Scientist and Visiting Lecturer. Currently Dr Abbasi is a Lecturer (Assistant Professor) in University of Glasgow in the School of Engineering in addition to Visiting Lecturer (Assistant Professor) with Queen Mary University of London (QMUL). Dr Abbasi has grant portfolio of around £3.5 million, contributed to a patent and more than 180 leading international technical journal and peer-reviewed conference papers, in addition to five books, and received several recognitions for his research. His research interests include nano communication, the Internet of Things, 5G and its applications to connected health, RF design and radio propagation, applications of millimetre and terahertz communication in healthcare and agri-tech, wearable and flexible sensors, compact antenna design, antenna interaction with human body, implants, body-centric wireless communication issues, wireless body sensor networks, non-invasive healthcare solutions and physical layer security for wearable/implant communication. Dr Abbasi is an IEEE senior member and was Chair of IEEE young professional affinity group. He is an Associate Editor for *IEEE Access* journal, *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, *Advanced Electromagnetics Journal* and acted as a guest editor for numerous special issues in top-notch journals including Elsevier's *Nano Communication Networks*. He is member of the IEEE 1906.1.1 standard committee on nano communication and is also a member of IET and committee member for the IET Antenna & Propagation and healthcare network. Dr Abbasi has been a member of the technical program committees of several IEEE flagship conferences and technical reviewer for several IEEE and top-notch journals. He contributed in organizing several IEEE conferences, workshop and special sessions in addition to a European School of Antennas course.

List of Contributors

Wasim Ahmad

School of Engineering
University of Glasgow
Glasgow

Nauman Aslam

Department of Computer Science and
Digital Technologies
Northumbria University
Newcastle

Konstantinos Antonakoglou

Department of Informatics
Kings College London

Islam Safak Bayram

Qatar Environment and Energy Research
Institute (QEERI)
Hamad Bin Khalifa University
Qatar

Mehrdad Dianati

Warwick Manufacturing Group (WMG)
University of Warwick
Coventry

Fabrizio Granelli

Department of Engineering and
Information Science
University of Trento
Italy

Chong Han

pureLiFi
Edinburgh

Sajjad Hussain

School of Engineering
University of Glasgow
Glasgow

Ali Imran

Artificial Intelligence for Networks
(AI4Networks) Lab
School of Electrical and Computer
Engineering
University of Oklahoma
Tulsa, USA

Matteo Innocenti

Azienda Ospedaliero-Universitaria
Careggi
Firenze
Italy

Muhammad Ismail

Electrical and Computer Engineering
Department
Texas A&M University at Qatar
Qatar

Kostas Katsaros

Digital Catapult
London

Stamos Katsigiannis

School of Engineering and Computing
University of the West of Scotland
Paisley

Paulo Valente Klaine

School of Engineering
University of Glasgow
Glasgow

Hoa Le-minh

Department of Mathematics, Physics and
Electrical Engineering
Northumbria University
Newcastle

Yi Lu

Warwick Manufacturing Group (WMG)
University of Warwick
Coventry

Maliheh Mahlouji

Department of Informatics
Kings College London

Toktam Mahmoodi

Centre for Telecommunications Research
Department of Informatics
Kings College London

Carsten Maple

Warwick Manufacturing Group (WMG)
University of Warwick
Coventry

Alex Mouzakitis

Department of Electrical, Electronics and
Software Engineering Research
Jaguar Land Rover
Coventry

João Pedro Battistella Nadas

School of Engineering
University of Glasgow
Glasgow

Huan Nguyen

Department of Design Engineering
and Mathematics
Middlesex University London

Rafaela de Paula Parisotto

Department of Electrical and
Electronics Engineering
Federal University of Santa Catarina
Brazil

Khalid Qaraqe

Electrical and Computer Engineering
Department
Texas A&M University at Qatar
Qatar

Haneya Naeem Qureshi

Artificial Intelligence for Networks
(AI4Networks) Lab
School of Electrical and Computer
Engineering
University of Oklahoma
Tulsa, USA

Naeem Ramzan

School of Engineering and Computing
University of the West of Scotland
Paisley

Mohsin Raza

Department of Design Engineering
and Mathematics
Middlesex University London

Usman Raza

Toshiba Research Europe Limited
Cambridge

Erchin Serpedin

Electrical and Computer Engineering
Department
Texas A&M University
College Station
Texas, USA

Luis Sequeira

Department of Informatics
Kings College London

David Soldani

Huawei
Australia

Richard D. Souza

Department of Electrical and
Electronics Engineering
Federal University of Santa Catarina
Brazil

Andy Sutton

British Telecom
Warrington
United Kingdom

Muhammad Usman

Department of Engineering and
Information Science
University of Trento
Italy

Preface

Recent technological advances have resulted in the creation of vertical industries that provide niche services that were hitherto non-existent only a decade ago. These industries are highly dependent on the availability and reliable exchange of data between multiple locations. As such, there is a consensus among analysts and opinion leaders that data will be the key driver in the fourth industrial revolution. Given the scale of devices to be connected in each vertical industry and the vast amount of data to be exchanged between multiple points, it is obvious that wireless communication is the leading enabler of the services envisioned by these industries. However, the current wireless communication systems have several technical limitations that would inhibit the actualization of the targets of these vertical industries. Hence, it is paramount to redesign wireless communication systems to take into account the holistic operational requirements of the vertical industries to enable them to reach the new productivity domains.

Mobile communication devices have rapidly evolved to become ubiquitous in our everyday lives. Although they were generally used for voice communication in the early days of the mobile communication system, steady advancement in research has paved the way for a significant increase in Spectral Efficiency (SE), which resulted in a paradigm shift towards wireless data communication. This transition has led to an increase in data rate from 50 kbps in 2G systems to 1 Gbps in the current 4G systems. Unfortunately, the popularity of wireless communications and the increasing demand for high data rates comes with the challenge of a dramatic increase in the energy consumption of these networks. Consequently, researchers had to focus on designing energy-efficient networks that would increase the amount of bits transmitted per joule of energy or reduce the energy required to transmit a bit of data.

Unlike existing generations of wireless communication systems that have simply been upgrades mostly in terms of SE and Energy Efficiency (EE), the fifth-generation mobile communication network (5G) seeks to bring about a revolution in the way mobile systems are perceived. It is envisioned that augmented reality, virtual reality, tele-robotics, remote surgery and haptic communication will be the revolutionary applications of 5G. Accordingly, 5G promises to stretch the limits of the Key Performance Indicators (KPIs) of current systems by taking into account several criteria such as latency, resilience, connection density and coverage area, alongside the traditional SE and EE criteria. 5G has design targets of sub-millisecond end-to-end latency, 100-fold increase in typical user data rates, 100 times increase in connection density and 10 times increase in EE,

compared to current systems. This makes 5G the prime candidate to support a wide range of vertical industries.

Given that each vertical industry has its specific requirements for optimal service delivery, the 5G communication system will have to provide tailor-made solutions for each industry against the “one size fits all anywhere, anytime” approach of current systems. In order to achieve this, novel techniques such as Software Defined Networking (SDN), Network Function Virtualization (NFV), new waveforms, carrier aggregation and network slicing would form the basis of 5G.

This book evaluates advances in the current state-of-the-art and provides readers with insights on how 5G can seamlessly support vertical industries. It explores the recent advances in theory and practice of 5G and beyond communication systems that provide support for specific industrial sectors such as smart transportation, connected industries, e-healthcare, smart grid, media and entertainment and disaster management. Furthermore, this book highlights how 5G and beyond communication systems can accommodate the unique frameworks and Quality of Service (QoS) requirements of vertical industries for efficient and cost-effective service delivery. Each chapter in the book is designed to focus on how 5G would enable a specific vertical industry.

Chapter 1 presents 5G network architecture, design and service optimization. The author introduces the latest Third Generation Partnership Project (3GPP) release of 5G (Release 15), which contains specifications of a new radio interface that connects to an enhanced evolved packet core, referred to as EPC+. The author also sheds light on the expected specifications of 3GPP Release 16, which will fully exploit 5G for vertical industries. Furthermore, the author describes 5G use cases families as identified by the Next Generation Mobile Networks (NGMN), which are broadband access in dense areas, broadband accessibility everywhere, higher user mobility, massive Internet of Things (IoT), extreme real-time communications, lifeline communications, ultra-reliable communications and broadcast-like services. These use cases enable support for various vertical industries. 5G network architecture is also introduced, with the author describing the new functional blocks, interfaces, control and user plane splitting, radio access network, as well as the integration of NFV and SDN to form a virtualized architecture. The chapter also covers the process of deploying a 5G network overlaid on current networks. The author concludes the chapter by proclaiming, “There is not an industry or business sector that will not be impacted by the introduction of 5G in support of an increasingly connected and automated digital workplace.”

In Chapter 2, the authors provide a comprehensive description of technology improvements, industrial processes and control requirements for the fourth industrial revolution. The authors make a case for and provide insights into how wireless sensor networks of the future can benefit from novel 5G technologies to improve efficiency in industrial processes. The chapter compares the typical QoS requirements of industrial applications based on battery life, security and update frequency, and then presents a detailed overview of the Industrial Wireless Sensor Network (IWSN) architecture, including node specifications, network topologies and channel access strategies. After highlighting the importance of Ultra-Reliable Low Latency Communication (URLLC) for IWSNs, the chapter proposes a hybrid multi-channel scheme for performance and throughput enhancement of IWSNs whereby multiple frequency channels are used to implement URLLC in IWSNs. The scheme utilizes a novel priority-based scheduler for retransmission of failed packets on a special frequency channel, and frequency polling

to mitigate collisions. This approach brings about a reduction in frame error rate, and improvement in reliability.

Chapter 3 presents the concept of haptic communication and examine the requirements for Tactile Internet to support haptic communication in terms of QoS, QoE and KPIs. Given that haptic teleoperation deals with a human operator controlling an actuator via a communication channel, the authors provide a classification of teleoperation systems based on the type of control system employed. Furthermore, they review the methodologies for teleoperation stability control and haptic data reduction, and then examine the necessary components of the haptic communication infrastructure by taking into account the 5G architecture, 3GPP components as well as the European Telecommunications Standards Institute (ETSI) NFV management and orchestration capabilities.

In Chapter 4, the authors examine how novel 5G concepts such as network slicing, cloud computing, SDN and NFV provide revolutionary features that perfectly fit the communication requirements of smart grid services. The authors provide an overview of future smart grid architecture and the services it is expected to support by categorizing them into data collection and management services. These services support enhanced grid monitoring, as well as control and operation services.

Chapter 5 provides an overview of the evolution of vehicular communication systems towards 5G and show how vehicular applications and services have changed over the years. The authors present a detailed description of the 3GPP specifications for cellular-based vehicle-to-everything (C-V2X) systems from Release 14 through the full standalone 5G system specifications in Release 16 on one hand, and the Dedicated Short-Range Communication (DSRC) on the other hand. Furthermore, a comparison is made between C-V2X and DSRC in terms of channel access, coverage, deployment cost and security among others. The authors also dwell on key 5G technologies that are enablers for V2X services and data dissemination for vehicular communication platforms that could support efficient cloud-based Intelligent Transportation Services (ITS) services through the use of middlewares. Additionally, the chapter analyses the evolution of V2X communication technologies alongside the services they support. The authors assert that there is still lack of insight on the required rollout investments, business models and expected profit for future ITS.

Chapter 6 assesses how the Sparse Code Multiple Access (SCMA) can be used to support high Quality of Experience (QoE) for drivers and passengers of Connected Autonomous Vehicles (CAVs). The authors describe the fundamental principle of SCMA and provide a comprehensive literature review of the advances made in the direction of SCMA as a candidate for 5G air interface, specifically in the case of CAVs. Moreover, the chapter identifies the gaps in the adoption of SCMA in vehicular communication systems.

In Chapter 7, the authors evaluate how URLLC would enhance healthcare delivery and examine two notable use cases – Wireless Tele Surgery (WTS) and Wireless Service Robot (WSR). WTS involves using robotic platforms with audio, video and haptic feedback to perform surgery in remote locations, while WSR deals with robots taking on the role of social caregivers for the sick and elderly in care homes. The authors describe the technical requirements for the implementation of these use cases and 5G key enabling technologies to meet the performance, dependability and security targets for Tele-healthcare. Included in the chapter is a detailed business model and cost analysis

that a Tele-healthcare provider would encounter when delivering the corresponding services on a 5G system.

In Chapter 8, the authors elucidate how 5G would disrupt the media and entertainment industry by enabling trends in audio-visual and immersive media. The authors identify the key challenges of this industry, which are capacity, latency and traffic prioritization, and show how 5G would support the services envisioned for the media industry. They start by providing a comprehensive overview of audio-video systems covering wireless audio use case in live production, video compression algorithms, streaming protocols and the requirements for video streaming over mobile networks by considering both practical and theoretical speeds of current mobile networks as well as 5G. With immersive media – augmented reality, virtual reality and 360-degree videos – being considered as the killer applications for 5G, the authors identify numerous use cases as well as the specific QoS requirements for each application and then show how these requirements are within the purview of 5G. In concluding the chapter, the authors posit, “the proliferation of 5G networks will spearhead the adoption of 360°/VR technology in various sectors of the (media) industry and everyday life, and become the catalyst for the expansion of the relevant market”.

Chapter 9 presents a realistic mathematical model for Unmanned Aerial Vehicle (UAV)-based cellular coverage that considers a practical directional 3D antenna. The chapter derives analytical expressions for coverage as function of UAV height, beamwidth and coverage radius, and analyses the trade-offs among these factors. Based on in-depth analysis on the effect of altitude and beamwidth on UAV coverage, the authors assert that antenna beamwidth is a more practical design parameter to control coverage, contrary to UAV altitude that is commonly used by researchers. Finally, the authors propose a novel hexagonal packing theory to determine the number of UAVs required to cover a given area.

In Chapter 10, the authors make a case for the use of UAVs to complement cellular systems in order to increase network capacity at certain locations or provide coverage in areas where the existing network cannot. They further present applications of UAVs in cellular networks such as communication in rural areas, data gathering from large-scale wireless sensor deployments, pop-up networks and emergency communications, among others. They then propose an intelligent UAV positioning framework for 5G networks, which leverages on reinforcement learning to determine the best location to deploy the swarm of UAV base stations in an emergency communication scenario.

Chapter 11 provides a comprehensive survey of public safety networks and their historical transition from analogue systems towards 5G. The authors describe the standardization efforts made to support the inevitable convergence of different public safety communication networks to incorporate narrowband and wideband systems as well as the recent trends in communication technologies by pointing out the activities of various standardization bodies such as 3GPP, Open Mobile Alliance, Alliance for Telecommunication Industry Solutions, APCO Global Alliance and Groupe Speciale Mobile Association (GSMA). They further identify connectivity, interoperability and security, among others, as the challenges faced by public safety networks and highlight key 5G technologies to mitigate these challenges.

Finally, in Chapter 12, we make a case for rural mobile data connectivity and the role of government in fast-tracking rural network deployment. Furthermore, we identify and

provide insights into some key technologies that would further the gains of 5G in terms of expanding the scope of 5G use cases and applications to new productivity spheres. These technologies include blockchain, terahertz communication, light fidelity (LiFi) and wireless power transfer and energy harvesting and are worth considering in the design of beyond 5G mobile communication systems.

1

Enabling the Verticals of 5G: Network Architecture, Design and Service Optimization

Andy Sutton

1.1 Introduction

5G is often referred to as the next generation of mobile communications technology. However, the potential is much more significant than this; 5G will likely become the future of communications, supporting fixed and mobile access. In addition to enhanced Mobile Broadband (eMBB), 5G will support Ultra-Reliable and Low-Latency Communications (URLLC), also referred to as Mission-Critical Communications, and massive Machine-Type Communications (mMTC) – an evolution of IoT, along with enabling Fixed and Mobile networks Convergence (FMC).

The ITU-R introduces the diverse requirements which 5G will address in recommendation ITU-R M.2083 (09/2015) [1]. These requirements are illustrated in Figure 1.1.

The December 2017 3GPP release of 5G, known as Release 15 phase 1, focused on eMBB use cases through the specification of a new radio interface which connects to an enhanced 4G LTE Evolved Packet Core (EPC) network. The enhanced EPC is referred to as an EPC+ and will likely be implemented using Network Functions Virtualisation infrastructure (NFVi) and therefore be a vEPC+. Because of this a 5G-capable device will connect to an enhanced Release 15 4G LTE radio base station (eNB) for control plane and 4G LTE and/or 5G radio for user plane traffic flows in what is known as Non-Stand-Alone (NSA) mode of operation. This combination of 4G LTE and 5G radio with a 4G EPC+ is what was known originally as an Option 3 architecture, of which Option 3x is the most popular variant. This architecture has been formalized within 3GPP as eUTRA and New Radio Dual Connectivity (EN-DC). While Release 15 doesn't deliver URLLC or mMTC, it doesn't mean there is no support for verticals; eMBB can support a range of use cases and offers a lower level of latency than existing 4G LTE networks. The additional network capacity that will be delivered through an EN-DC architecture will ensure network performance is enhanced while new use cases such as Fixed Wireless Access (FWA) and Hybrid access in which fixed broadband is combined with 5G radio access will enable new business and service opportunities. The 3GPP Release 15 EN-DC architecture is illustrated in Figure 1.2.

To fully exploit 5G for vertical industries it will be necessary to implement the 5G Next Generation Core (NGC) network along with NR. This delivers a full 5G end-to-end

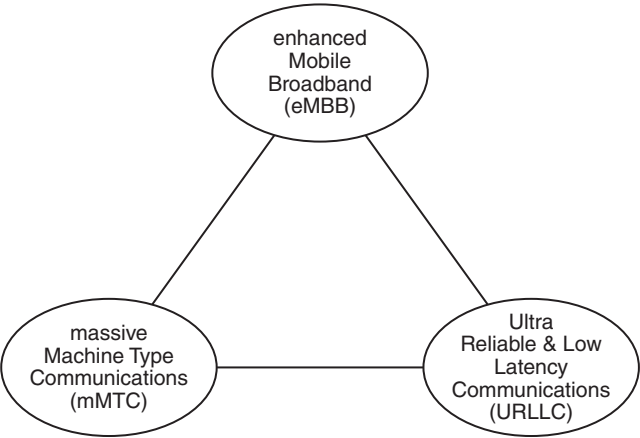


Figure 1.1 Diverse network requirements of 5G.

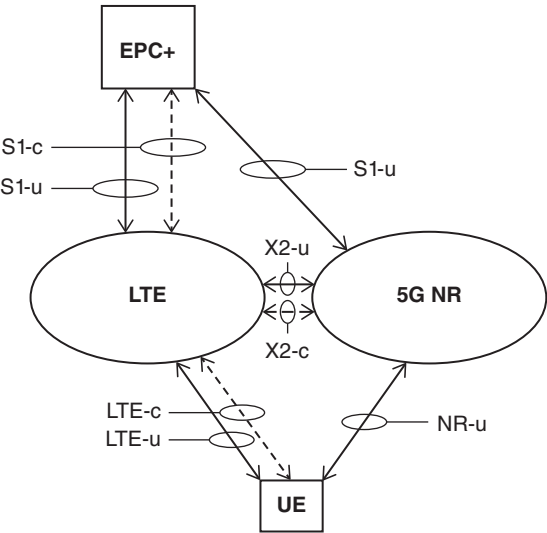


Figure 1.2 3GPP EN-DC network architecture.

network as specified by 3GPP. There is a Stand-Alone (SA) version of 5G once the NGC becomes available. However, many networks will implement NGC is what was originally known as an Option 7 network architecture (Option 7x being the most common variant) in which the radio control plane will remain on 4G LTE due to the probability of superior 4G LTE radio coverage in the early days of 5G rollout while the user plane will be on 5G radio and/or 4G LTE. This dual connectivity solution with a 5G NGC has been specified by 3GPP as Next Generation eUTRA and New Radio Dual Connectivity (NGEN-DC). Once 5G coverage is equivalent to or better than 4G LTE the control plane can be switched to the 5G radio base station, known as a gNB. It is anticipated that in the fullness of time mobile operators will re-farm their 4G LTE radio spectrum to 5G NR; however, this is expected to take many years, considering how much spectrum is still being utilized for older 2G GSM/GPRS and 3G UMTS/HSPA networks.

1.2 Use Cases

A 5G end-to-end network, with or without dual connectivity with 4G LTE, will support a wide range of use cases. The Next Generation Mobile Networks (NGMN) Alliance's 5G white paper [2] presents the 5G services as eight use case families and highlights a single example of each use case family, noting that there are many other use cases within each family which will address a wide range of connectivity requirements. Example use cases are illustrated in Figure 1.3.

The true diversity of capability requirements which 5G must address are illustrated in Figure 1.3, from eMBB use cases to those requiring low-latency and/or ultra-reliable communications along with use cases which will require mMTC. The forecast for growth of the Internet of Things has led to the ITU-R specifying the need for mMTC to support up to 1,000,000 devices per km².

eMBB will address broadband data access in dense urban areas through the provision of very high area capacity density while also addressing the opposite extreme of broadband access everywhere, which targets 100% geographical coverage. Broadband on trains is a key use case for higher user mobility, which will require a reliable eMBB connection albeit reliability at such high speeds will bring unique challenges. Other use cases for higher user mobility include mobile broadband connectivity to aircraft, as demonstrated with the implementation of the European Aviation Network (EAN) [3] and future use cases involving drones. The massive Internet of Things will make use of mMTC, likely an evolution of 4G LTE Narrow-band – IoT (NB-IoT) technology to provide the capability to support up to 1 million devices per square kilometre. Use case families, extreme real-time communications, lifeline communications and ultra-reliable communications will really stretch the capabilities of 5G. Capabilities of eMBB and mMTC will be used for certain use cases within these families. However, the use of URLLC, be this ultra-reliable and/or low-latency communications, will consume significant resources from the network, effectively shrinking radio coverage and reducing capacity as reliability and/or low-latency targets become more extreme [4]. The last use

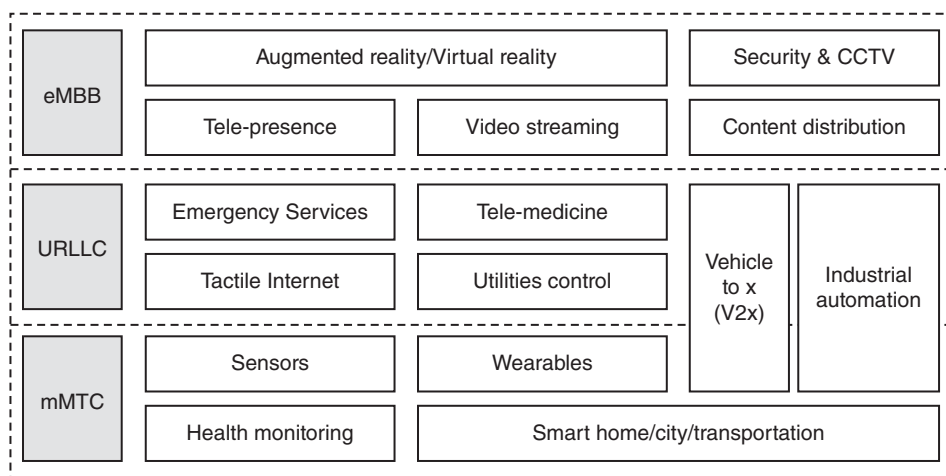


Figure 1.3 Example use cases for 5G network capabilities.

case family is broadcast-like services; an evolution of 4G LTE enhanced Multimedia Broadcast Multicast Service (eMBMS) coupled with IP multicast within the transmission network, this will enable efficient distribution of mass market real-time content such as live sports or news and support multicast use cases from retailers and other verticals.

1.3 5G Network Architecture

A 5G end-to-end network supports subscriber data management, control plane functions and user plane functions. Since the early days of Global System for Mobile Communications (GSM) and then General Packet Radio Service (GPRS), the mobile eco-system has been familiar with logical representations of mobile network architectures. These diagrams take the form of functional blocks and the interfaces between them, officially known as reference points. Figure 1.4 presents this view of the 3GPP 5G network, referred to as “reference point representation”.

The reference points or interfaces, which will be known as interfaces for the remainder of this chapter, start with the letter “N”. Originally these were designated “NG” for next generation. However, recently the term has been shortened to simply read “N”. The functional blocks are split between control plane and user plane functions, with the control plane further split between subscriber management functions and control plane functions. The subscriber management functions consist of the Authentication Server Function (AUSF) and Unified Data Management (UDM), an evolution of the Home Subscriber Service (HSS). The control plane function consists of a core Access and Mobility management Function (AMF), a Session Management Function (SMF), Policy Control Function (PCF), Application Function (AF) and Network Slice Selection Function (NSSF). The NSSF is responsible for selecting which core network instance is to accommodate the service request from a User Equipment (UE) by considering the UE’s subscription and any specific parameters. The user plane path starts with the UE, which

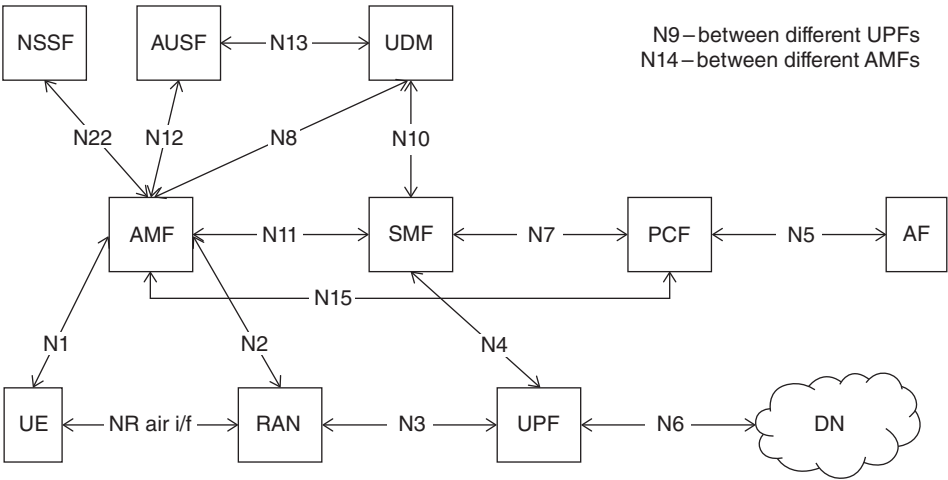


Figure 1.4 5G network architecture – reference point representation.

may be a smartphone or a new form factor terminal, possibly fixed rather than mobile. The UE connects via the Radio Access Network (RAN) to the User Plane Function (UPF) and on to a Data Network (DN). The DN may be the public Internet, a corporate intranet or an internal services function within the mobile network operator's core (including content distribution networks).

The NR air interface downlink waveform is Cyclic Prefix-Orthogonal Frequency Division Multiplex (CP-OFDM) access while the uplink can be either CP-OFDM or Discrete Fourier Transform-spread-Orthogonal Frequency Division Multiple (DFT-OFDM) access, the uplink mechanism being selected by the network based on use case. The UE connects to the RAN via the air interface, which also carries the N1 interface, which in previous iterations of 3GPP technologies has been known as the non-access stratum. The N1 interface is a secure peer to peer control plane communication between the UE and core AMF. The N2 and N3 interfaces comprise what is commonly known as mobile backhaul between the RAN and the core network although, as we'll discuss shortly, this isn't as simple in reality as the illustration in Figures 1.4 and 1.5 suggest. The N6 interface provides connectivity between the UPF and any internal or external networks or service platforms. The N6 interface will include connectivity to the public Internet and will therefore contain the necessary Internet-facing firewalls and other smarts associated with the evolution of the Gi/SGi LAN environment. The Gi/SGi LAN environment has evolved from GPRS through UMTS and LTE to provide a range of capabilities in support of mobile data network operation, including features such as Transmission Control Protocol (TCP) optimization, deep packet inspection and network address translation.

In addition to the familiar logical network diagram with defined interfaces, 3GPP has introduced an alternative view of the 5G network architecture which is known as Service-Based Architecture (SBA). SBA takes advantage of recent developments in Network Functions Virtualisation and Software Defined Networking to propose a network based on virtualized infrastructure. This architecture will leverage service-based interactions between control plane functions as necessary. The solution will sit on

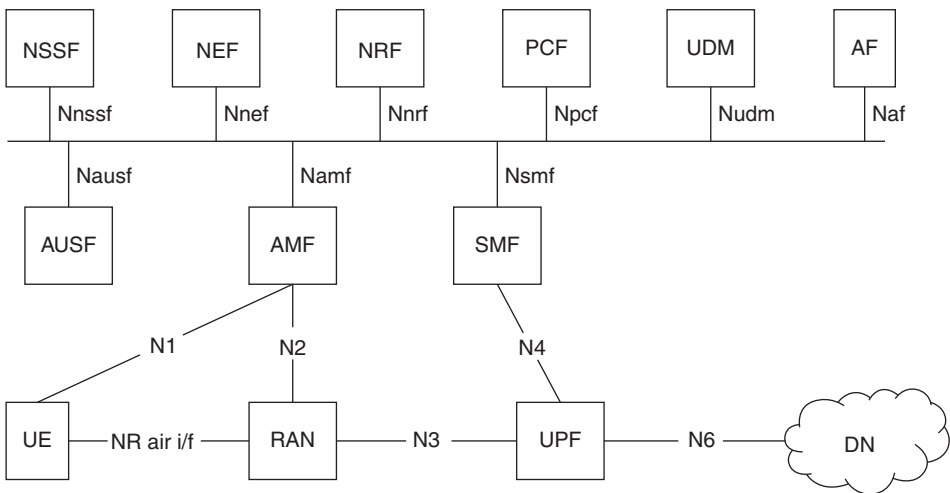


Figure 1.5 5G service-based architecture.