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SOFTWARE DEFINED MOBILE NETWORKS (SDMN)

BEYOND LTE NETWORK ARCHITECTURE

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Foreword

Originally, the Internet was designed as a decentralized packet switching network that is multiply redundant, fault-tolerant and with mostly peripheral computational components. Today, the Internet has usurped the majority of all information and communications technology (ICT) functions in society, spanning the range of media access services such as television, music and video streaming, Web access, and interactive telecommunications (voice and video telephony), as well as supporting a diverse range of applications that connect machine devices in various environments to each other and to the network. In parallel, the relentless reduction in price, power consumption, and device size driven by Moore's law has led to computation, storage, and networking becoming so inexpensive that intelligence can be incorporated into almost all manufactured goods. Enterprise IT systems are also rapidly being centralized with cloud technologies, creating huge efficiencies in the way computation, networking, and storage are provisioned and deployed. The broad impact that the Internet and inexpensive computation are having on life is leading to a networked society, in which anything that would benefit from being connected, will be connected.

Central among the supporting technologies for a networked society are mobile networks which provide connectivity both for the devices that constitute the Internet of Things, as well as for devices used for communication by people. Mobile networks face increasing challenges going forward as the characteristics of the data transported over them will vary widely, from large volumes of small and periodic sensor readings to large high-definition video streams. New services such as vehicular communications and critical infrastructure for industrial applications of the Internet pose exacting requirements on security, latency, and reliability. Mobile operators must build and provision their networks to accommodate this flood of data, and simplify the way new services are defined and provisioned in accordance with their customers' needs. Vendors must in turn provide operators with systems that solve the posed challenges in a cost-effective manner.

Fortunately, new technologies in the pipeline will help the ICT industry rise to the challenge. Cloud computing and software defined networking (SDN), originally developed in enterprise networks, are now moving into operator networks, including mobile networks, through the European Telecommunication Standards Institute (ETSI) Network Function Virtualization

(NFV) effort. The articles in this book address important research questions in software defined mobile networking (SDMN), and represent the fruits of academic and industrial research over the recent years. Research in SDMN, such as that described in this volume, will play a critical role in defining NFV and in the 5G mobile network.

Ulf Ewaldsson
Senior Vice President, Chief Technology Officer
Ericsson

Foreword

Mobile networking is entering an exciting era of development, driven both by user needs and new technologies. Key new technologies are network function virtualization (NFV) and software defined networking (SDN). They are often considered together or even confused with each other. Simplified, NFV separates the network functions from the underlying hardware and software platforms, whereas SDN separates network control from the user data routing. They bring benefits in capacity scaling, cost reduction, and flexibility and speed in the introduction of new services. NFV concepts are already rather broadly agreed, for example, via the ETSI specification work and NFV-based products are entering into commercial service. Similar broad agreement on how to utilize SDN in mobile networks is missing, so this book is a timely contribution to that discussion. To get the full benefit of NFV and SDN in mobile networks, we need to take a new look at the network architecture as it now stands.

This book takes that look, both broad and deep. It introduces current state of the art and probes potential ways to evolve mobile networks to take better advantage of SDN and NFV. It discusses system wide and product architectures and key issues like network management, quality of service, and security. The technologies exposed in this book are central to the evolution of mobile networking and future definition of the 5G architecture. While there are no final answers, yet the book provides a good update on the leading edge of research in SDN and NFV for mobile networks.

Lauri Oksanen
VP, Research and Technology
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Preface

The main objective of this book is to provide the cutting-edge knowledge about software defined mobile network (SDMN) architecture. SDMN is one of the promising technologies that are expected to solve the existing limitations in current mobile networks. SDMN architecture provides the required improvements in flexibility, scalability, and performance to adapt the mobile network to keep up with the expected future mobile traffic growth.

This book gives an insight into the feasibility of SDMN concept and its opportunities. It also evaluates the limits of performance and scalability of the SDMN architecture. The book discusses theoretical principles of beyond long-term evolution (LTE) mobile network architectures and their implementation aspects.

The SDMN architecture is based on software defined networking (SDN) and network virtualization principles. The book aims at evaluation, specification, and validation of SDN and network function virtualization (NFV) relevant to future SDMNs. The SDMN concept will change the network architecture of the current LTE mobile networks. It is foreseen that SDMN architecture will offer new opportunities for traffic, resource, and mobility management. Moreover, it will introduce new challenges on network security and impact on the cost of the network, value chain, business models, and the investments on mobile networks. This book presents a well-structured, readable, and complete reference of all these aspects of SDMN architecture. It contains both introductory level text as well as more advanced reference to meet the expectation of readers from various backgrounds and levels.

The Need for SDMN

The first mobile telecommunication network was introduced in the 1980s. During past four decades, the mobile communication technologies have achieved a significant development. The evolving mobile services, rapidly increasing broadband speed and inherent mobility support attract many subscribers. Thus, mobile communication is becoming the primary or even sole access method for more and more people. The present mobile networks support sophisticated network services such as Voice over IP (VoIP), high-density video streaming, high-speed broadband connectivity, and mobile cloud services. As a result, the mobile traffic volume is drastically increasing in each year. It is foreseen that the mobile data traffic usage is growing faster than the fixed Internet for the coming years. Thus, mobile networks must upgrade to keep up with the traffic growth and support rapidly evolving mobile services market. However, it is always challenging to increase the mobile network bandwidth due to the limited radio bandwidth resources and remarkably complex and inflexible backhaul devices.

On the other hand, the present business environment of telecommunication is changing rapidly. Usually, the telecommunication market is highly competitive. However, today's mobile operators must compete with a new class of competitors such as over-the-top (OTT) players, cloud operators, and established Internet service provider (ISP) giants. Thus, it is required to minimize CapEx of the network by reducing the cost of hardware and minimize OpEx by maximizing the utilization from hardware assets. In order to overcome these challenges, mobile networks have not only to go through architecture processes to optimize the current resources but also to add new components/technologies which increase the capacity.

On these grounds, SDN and NFV are promising technologies which are expected to solve these limitations in current mobile networks. SDN provides the required improvements in flexibility, scalability, and performance to adapt the mobile network to keep up with the expected growth. NFV offers a new way to design, deploy, and manage networking services. NFC allows decoupling the network functions from proprietary hardware appliances, so they can run in software. SDMN architecture is based on both SDN and NFV principles.

The adaptation of SDN concepts is expected to solve many limitations in current mobile networks. In SDN enables telecom networks, each operator has the flexibility to develop new networking concepts, optimize their network, and address specific needs of subscribers. Furthermore, software-programmable network switches in SDMN use modern agile programming methodologies. These software methodologies can be developed, enhanced, and upgraded at much shorter cycles than the development of today's state-of-the-art mobile backhaul network devices.

SDN and NFV Development

During the past few decades, many similar initiatives such as Telecommunications Information Networking Architecture (TINA), intelligent networks, and active networks which were proposed to solve the flexibility, scalability, and performance issues in telecommunication networks. These architectures were not finally realized due to failures at the implementation stage and the lack of support from industrial giants. However, the adaptation of SDN and NFV concept has extended up to commercial production level already. Almost all the device manufactures are working on the designing of devices to support SDMNs. Some telecommunication device manufactures already started to ship SDMN products for mobile network operators.[1]

[1] Josh Taylor, Telstra taps Ericsson for software defined networking, Technical report, 2014, URL http://www.zdnet.com/au/telstra-taps-ericsson-for-software defined-networking-7000032689/.

On the one hand, we have seen plenty of innovation in devices we use to access the network, the applications, and services. However, the network infrastructure has always consisted of remarkably complex and inflexible devices. The rapid traffic growth has demanded a significant change in these devices. The SDMN architecture changes the underlying infrastructure of telecommunication networks. Both SDN and NFV concepts are offering new ways to design, build, and operate the telecommunication networks.

The adaptation of SDN concepts propose to decouple the control plane from the data plane and make the control plane remotely accessible and remotely modifiable via third-party software clients. Thus, it is directing the current mobile network toward a flow-centric model that employs inexpensive hardware and a logically centralized controller. NFV concepts enable ubiquitous, convenient, on-demand network access to a shared pool of configurable network resources.

Thus, SDN and NFV concepts create a new telecommunication network environment which can support rapid service innovation and expansion. It also scales and optimizes the utilization of network resources more efficiently and cost effectively without compromising customer's experience.

SDMN Standardization

Many standardization bodies already started standardization efforts on SDMN concepts. Standardization is the first step toward the wide adoption of a new technology. Thus, the benefits of such standardization efforts are very significant for all stakeholders of the telecommunication field.

European Telecommunications Standards Institute (ETSI) is an industry-led standards development organization. It is the biggest telecommunication community which is working on the adaptation of NFV concepts for future mobile networks since 2012. Initially, seven of the world's leading telecoms network operators started Industry Specification Group for NFV (ISG NFV) at ETSI. During the past 2 years, this group has grown significantly. ISG NFV is now consisting of over 220 individual companies including 37 of the world's major service providers. This large community of experts are working intensely to develop the required standards for NFV as well as sharing their experiences of NFV development and early implementation.

On the other hand, Open Networking Foundation (ONF) is a non-profit organization dedicated to accelerating the adoption of open SDN, and it is the leading standardization organization in SDN domain. ONF was founded in 2011, and the membership of ONF as grown to over 100 company-members including telecom operators, network service providers, equipment vendors, and virtualization software suppliers. In 2014, ONF has formally launched one working group called Wireless & Mobile Working Group (WMWG). WMWG analyzes architectural and protocol requirements for extending SDN technologies to wireless and mobile domains include wireless backhaul networks and cellular Evolved Packet Core (EPC).

These two communities have started to share their standardization works since 2014. ETSI signed a strategic partnership agreement with ONF to further the development of NFV specifications by utilizing SDN concepts.

Furthermore, several Study Groups (SGs) of ITU (International Telecommunication Union)'s Telecommunication Standardization Sector (ITU-T) are already working on the adaptation of SDN concepts for public telecommunication networks. For instance, SG13 (Future networks) is focusing on functional requirements and architecture development for SDN enabled mobile networks. SG11 (signaling) works aligns with SG13 to develop signaling requirements and protocols for their SDN architectures.

Moreover, various other research communities such as Software Defined Networking Research Group (SDNRG) in Internet Engineering Task Force (IETF), Optical Internet Forum (OIF), Broadband Forum (BBF), and the Metro Ethernet Forum (MEF) are also working of the SDN and NFV deployment in various network scenarios.

It is always tricky to predict what will be the future of telecommunication networks beyond the LTE architecture. However, the benefits of applying the SDMN principles and the tremendous support by both the research community and the industry giants make SDMN a very promising candidate for future mobile networks.

Intended Audience

The book will be interesting for Industry/SMEs to design new telecommunication devices, network engineers implementing new technologies in the operator network, researchers working in the area of next-generation mobile network, and students working on master or doctoral theses in the areas of network security, mobility management, and Techno-economics.

This book provides a cutting-edge knowledge in areas such as network virtualization and SDN concepts relevant to next-generation mobile networks. This helps Industry/SMEs to create innovative solutions based on the research results in this book. It can be transferred to their products enabling the company to maintain its competitiveness in the challenging telecommunication market. Network operators can gain knowledge on latest network concepts such as SDN and virtualization. Also they can foresee the advantages of SDMN in terms of cost savings, scalability, flexibility, and security. The new possibilities of SDMN concept can help operators to cope with the increased cost pressure and competition.

Finally, this book facilitates the transfer of up-to-date telecommunication knowledge to university students and young scientists in research institutes and universities. Furthermore, the book will provide a complete introduction of SDMN concept for fresh researchers in the field. On the other hand, the book includes an overview of several related research areas such as virtualized transport/network management, traffic, resource and mobility management, mobile network security, and techno-economic modeling.

Organization of the Book

The book is organized into five parts: (I) Introduction, (II) SDMN architectures and network implementation, (III) Traffic transport and network management, (IV) Resource and mobility management, and (V) Security and techno-economic aspects.

The first part includes a general overview and background on SDN and present mobile network architectures. It presents the brief history and evolution of both SDN concepts and mobile network architectures. In the overview (Chapter 1), we present the SDMN architecture. Initially, we discuss the limitations of present-day mobile architectures. Then, we explain the advance features and key benefits of SDMN architecture. Chapter 2 presents the evolution of mobile networks. It analyzes the market trends and traffic projections of mobile communication.

Based on that, this chapter also explains requirements in future mobile networks. Chapter 3 explains the general SDN concepts. The chapter presents the history, the evolution and various application domains of SDN. It also provides a short summary of some of the prominent SDN related activities in industry and standardization bodies. Chapter 4 examines how the SDN concept and technologies could be applied in the wireless world. This chapter reviews opportunities and challenges which will happen during the adaptation of SDN concepts to wireless networks. Chapter 5 presents the role of SDN in the design of future 5G wireless networks. It also contains a survey on the emerging trends, prospects and challenges of SDN based 5G mobile systems.

The second part covers the basic of SDMN architectures and various implementation scenarios. It provides the state of the art in SDMN and describes changes to the current LTE architecture which is useful for wider SDMN deployment. Part II starts with Chapter 6 which provides an overview of LTE network architecture and its migration towards SDN based mobile network. This chapter describes how SDN based mobile networks benefit both mobile operators and end users. Chapter 7 presents a deployment model of the evolved packet core (EPC) where the EPC functions are deployed as services on a virtualized platform in a cloud computing infrastructure. It also explains the advantages of SDN which offers the potential to integrate the EPC services into the broader operator network using cross-domain orchestration. Chapter 8 discusses important aspects of the controller placement problem (CPP) in software defined mobile networks (SDMN). It presents the available solution methodologies and analyzes relevant algorithms in terms of performance metrics. Chapter 9 analyzes the factors influencing the future evolution of telecommunication clouds controlled by open-source platform software.

The third part discusses the impact of SDN concepts on traffic transport and network management functions of future mobile networks. It also explains the scalability of SDMNs and optimization of traffic transportation in SDMNs. Chapter 10 describes the European Telecommunications Standards Institute (ETSI) Network Function Virtualization (NFV) architecture and underlying support provided by SDN in the mobile network context. Chapter 11 introduces the main building blocks of traffic management in mobile networks, and provides an overview of quality of Servic (QoS) provisioning and dynamic policy control in 3G/4G networks. Then, it discusses the QoS enforcement features of OpenFlow switches and presents a future technology for improved resource selection using the application-layer traffic optimization protocol integrated into software defined networks. Chapter 12 describes the applicability of SDN to mobile applications by allowing dynamic service chaining inside the packet core, radio access networks and between user equipment (UE) for direct device-to-device communication. Chapter 13 provides platforms and technologies used for load balancing in software defined mobile networks. It also discusses the main challenges existing in current load balancing technologies and explains the requirements of novel load balancing technologies for software defined mobile networks.

The fourth part explains the various challenges on resource and mobility management of future mobile networks while adapting the SDN concepts. Chapter 14 presents the SDN enabled QoE monitoring and enforcement framework for Internet services. This framework augments existing quality-of-service functions in mobile as well as software defined networks by flow based network centric quality of experience monitoring and enforcement functions. Chapter 15 discusses SDN-based mobility management in the Internet. It reviews existing Internet mobility protocols and explains why SDN is beneficial to solve current Internet mobility problems. Chapter 16 reviews the existing MVNO architectures and explains the limitation in current architectures. Moreover, it explains SDN perspective of MVNOs which adds the reconfigurable mobile network parameters to the existing MVNO and enhances the features of the mobile network.

The fifth part covers the security and techno-economic aspects. It includes comprehensive literature review in security challenges in future mobile architectures and security management aspects in SDMNs. Moreover, it discusses the business cases in virtualized mobile network environments and presents both evolutionary and revolutionary industry architectures for SDMNs. Chapter 17 explains the limitation on traditional security models and presents the requirement to develop an inclusive and intrinsic security model across the SDMN. Chapter 18 presents the security issues introduced by SDN, NFV and future mobile networks that integrate these technologies to become software defined mobile networks (SDMNs). Finally, Chapter 19 defines the key business roles and presents both evolutionary and revolutionary industry architectures for SDMN, as well as discusses the perspectives of different stakeholders in the mobile network industry.

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Madhusanka Liyanage, Andrei Gurtov, and Mika Ylianttila

Abbreviations

1G	First generation
2G	Second generation
3D	Three-dimensional
3G	Third generation
3GPP	Third-Generation Partnership Project
4G	Fourth generation
5G	Fifth generation
AAA	Authentication, authorization, and accounting
ACID	Atomicity, consistency, isolation, and durability
ACK	Acknowledgment
ADC	Application Detection and Control
ADC	Application delivery controllers
ADSL	Asymmetric digital subscriber line
AF	Application function
AKA	Authentication and key agreement
ALTO	Application-layer traffic optimization
AMPS	Advanced mobile phone system
AN	Access network
API	Application programming interface
APLS	Application label switching
APN	Access Point Name
APN-AMBR	Per APN aggregate maximum bit rate
APS	Access point services
APT	Advance persistent threat
AQM	Active queue management
ARP	Address Resolution Protocol
ARP	Allocation and retention priority
AS	Access stratum
AS	Autonomous system

ASS	Application Service Subsystem
ATM	Asynchronous Transfer Mode
BBERF	Bearer Binding and Event Reporting Function
BBF	Broadband Forum
BGP	Border Gateway Protocol
BR	Business revenue
BS	Base station
BSC	Base station controller
BSS	Base station subsystem
BSS	Business service subsystem
BT	Business tariff
BTR	Bit transfer rate
BTS	Base transceiver station
BYOD	Bring your own device
CAGR	Compound annual growth rate
CAM	Content-addressable memory
CAP	Cognitive access point
CapEx	Capital expenditure
CAPWAP	Control and Provisioning of Wireless Access Points
CBTC	Communication-Based Train Control
CCNs	Content-centric networks
CDF	Cumulative distribution function
CDMA	Code division multiple access
CDN	Content delivery network
CDNI	Content Delivery Networks Interconnection
CE	Control element
CES	Customer edge switching
CGE	Carrier-grade Ethernet
CG-NAT	Carrier-grade network address translation
CGW	Charging gateway
CIA	Confidentiality, integrity, and availability
C-MVNO	Cognitive mobile virtual network operator
CN	Core network
CoA	Care-of address
COTS	Commercial off the shelf
CP	Control plane
CPP	Controller placement problem
CPU	Central processing unit
C-RAN	Cloud—radio access network
CRM	Cognitive radio management
D2D	Device to device
DDoS	Distributed denial of service
DFI	Deep flow inspection
DHCP	Dynamic Host Configuration Protocol
DiffServ	Differentiated services
DL	Downlink

DMM	Distributed mobility management
DNS	Domain name server
DoS	Denial of service
DP	Data plane
DPDK	Data Plane Development Kit
DPI	Deep packet inspection
DSCP	Differentiated services code point
DSL	Digital subscriber line
DTLS	Datagram Transport Layer Security
EAP	Extensible Authentication Protocol
EAP-AKA	Extensible Authentication Protocol—Authentication and Key Agreement
EAP-SIM	Extensible Authentication Protocol—Subscriber Identity Module
EC2	Elastic Compute Cloud
ECMP	Equal-cost multipath
EDGE	Enhanced data rates for GSM evolution
EID	Endpoint identifiers
EM	Element manager
Email	Electronic mail
eNodeB	Enhanced NodeB
EPC	Evolved packet core
ePCRF	Enhanced Policy and Charging Rules Function
EPS	Evolved packet services
E-RAB	Evolved radio access bearer
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved UMTS terrestrial radio access network
EVDO	Evolution-Data Optimized
FE	Forwarding element
FLV	Flash video
FM	Frequency modulation
FMC	Fixed–mobile convergence
ForCES	Forwarding and Control Element Separation
FQDN	Fully qualified domain name
FRA	Future radio access
FTP	File Transfer Protocol
FW	Firewalls
GBR	Guaranteed bit rate
GENI	Global Environment for Networking Innovations
GGSN	Gateway GPRS Support Node
GPL	General public license
GPRS	General Packet Radio Service
GRX	GPRS roaming exchange
GSM	Global System for Mobile Communications
GTP	GPRS Tunneling Protocol
GUTI	Globally Unique Temporary Identity
H2020	Horizon 2020
HA	Home agent

HA	High availability
HAS	HTTP Adaptive Streaming Services
HD	High definition
HeNB	Home eNodeB
HetNet	Heterogeneous network
HFSC	Hierarchical fair-service queue
HIP	Host Identity Protocol
HLR	Home location register
HLS	HTTP live streaming
HMAC	Hash message authentication code
HMIPv6	Hierarchical mobile IPv6
HoA	Home address
HRPD	High-rate packet data services
HSPA	High-speed packet access
HSS	Home Subscriber Server
HTB	Hierarchical token bucket
HTTP	Hypertext Transfer Protocol
I2RS	Interface to the Routing Systems
IaaS	Infrastructure as a service
IA-MVNO	Intramodular mobile virtual network operator
ICN	Information-centric networks
ID	Identifier
IDPS	Intrusion Detection and Prevention Systems
IDS	Intrusion Detection System
IEEE	Institute of Electrical and Electronics Engineers
IE-MVNO	Intermodular mobile virtual network operator
IETF	Internet Engineering Task Force
ILNP	Identifier/Locator Network Protocol
ILS	Identifier/Locator Split
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IP	Internet Protocol
IPsec	Internet Protocol security
IPTV	Internet Protocol television
IPX	Internetwork Packet Exchange
ISAAR	Internet Service quality Assessment and Automatic Reaction
ISP	Internet service providers
ISV	Independent software vendor
IT	Information technology
ITU	International Telecommunication Union
KASME	Key Access Security Management Entity
KPI	Key Performance Indicator
L1	Layer 1
L2	Layer 2
L3	Layer 3

L4	Layer 4
L7	Layer 7
LAN	Local area network
LISP	Locator Identifier Separation Protocol
LMA	Local mobility anchor
LR-WPAN	Low-rate wireless personal area networks
LSP	Label-switched path
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution-Advanced
M2M	Machine to machine
MaaS	Mobility as a service
MAC	Media access control
MAC	Message authentication code
MAG	Mobile Access Gateway
MANO	Management and orchestration
MAP	Mobility anchor points
MBR	Maximum bit rate
MCP	Multiple controller placement
ME	Mobile equipment
MEF	Metro Ethernet Forum
MEUN	Mobile end user nodes
MEVICO	Mobile Networks Evolution for Individual Communications Experience
MIMO	Multiple input and multiple output
MIP	Mobile IP
MIPv6	Mobile IPv6
MLB	Mobility load balancing
MM	Mobility management
MME	Mobility management entity
MNO	Mobile network operator
MO	Mobile operator
MOS	Mean Opinion Score
MPG	Mobile Personal Grid
MPLS	Multiprotocol label switching
MSC	Mobile switching center
MSOP	Mobile virtual network operator service optimization
MSS	Mobile switching systems
MTC	Machine-type communications
MTU	Maximum transmission unit
MVNA	Mobile virtual network aggregator
MVNE	Mobile virtual network enabler
MVNO	Mobile virtual network operator
MVO	Mobile virtual operator
NaaS	Network as a service
NAS	Nonaccess stratum
NAT	Network address translation
NBI	Northbound interface

NBS	Name-based sockets
NFV	Network function virtualization
NFVI	Network function virtual infrastructure
NFVO	Network function virtualization orchestrator
NGN	Next-generation network
NIDS	Network Intrusion Detection Systems
NMS	Network monitoring system
NNSF	NAS Node Selection Function
NOMA	Nonorthogonal multiple access
NOS	Network operating system
NRM	Network resource manager
NSC	Network service chaining
NSD	Network Service Descriptor
NSN	Nokia Solutions and Networks
NSS	Network Service Subsystem
NVP	Network virtualization platform
OAM	Operation and management
OF	OpenFlow
OFDM	Orthogonal frequency division multiplexing
OIF	Optical Internet Forum
ONF	Open Network Foundation
OpenSig	Open signaling
OpEx	Operational expenditure
OS	Operating system
OS3E	Open Science, Scholarship, and Services Exchange
OSS	Optimal subscriber services
OTT	Over the top
OVS	Open virtual switch
OWR	Open wireless architecture
P2P	Peer to Peer
P4P	Provider Portal for P2P Applications
PaaS	Platform as a service
PC	Personal computers
PCC	Policy Control and Charging
PCEF	Policy Control Enforcement Function
PCRF	Policy and Charging Rules Function
PDCP	Packet Data Convergence Protocol
PDN-GW	Packet Data Network Gateway
PDP	Packet Data Protocol
PDSN	Packet Data Serving Node
PFB	Per-flow behavior
P-GW	Packet Data Network Gateway
PID	Provider-defined identifier
PIN	Place in the network
PKI	Public key infrastructure
PMIPv6	Proxy Mobile IPv6

PO	Primary operator
PoC	Push over cellular
POP	Points of presence
POS	Packet over SONET
POTS	Plain old telephone systems
PPP	Point-to-Point Protocol
PR	Path Record
PSTN	Public switched telephone network
PTT	Push to talk
QCI	QoS class identifier
QEN	Quality enforcement
QMON	Quality monitoring
QoE	Quality of experience
QoS	Quality of service
QRULE	Quality rules
RAN	Radio access network
RAP	Radio access point
RBAC	Role-based access control
REST	Representational State Transfer
RF	Radio frequency
RFC	Request for Comments
RLOC	Routing locators
RLSE	Regional-level spectral efficiency
RMON	Remote monitoring
RNAP	Resource Negotiation and Pricing
RNC	Radio network controller
ROI	Return of investment
RPC	Remote Procedure Calls
RRC	Radio Resource Control
RRM	Radio Resource Management
RTP	Real-Time Transport Protocol
RTT	Round-trip time
S/P-GW	Serving/Packet Data Network
SaaS	Security as a service
SaaS	Software as a service
SAE	System architecture evolution
SatCom	Satellite communication
SBC	Session border controller
SBI	Southbound interface
SCTP	Stream Control Transmission Protocol
SD	Standard definition
SDM	Software-defined monitoring
SDM CTRL	Software-defined monitoring controllers
SDMN	Software-defined mobile networks
SDN	Software-defined networks
SDNRG	Software-Defined Networking Research Group

SDP	Session Description Protocol
SDR	Software-defined radio
SDS	Software-defined security
SDWN	Software-defined wireless networks
SENSS	Software-defined security service
SG	Study groups
SGSN	Serving GPRS Support Node
S-GW	Serving Gateways
SHA	Secure Hash Algorithm
SID	Service identifier
SIEM	Security Information and Event Management
SIGMONA	SDN Concept in Generalized Mobile Network Architectures
SILUMOD	Simulation Language for User Mobility Models
SIM	Subscriber identity module
SINR	Signal-to-interference-plus-noise ratio
SIP	Session Initiation Protocol
SLA	Service-level agreement
SMS	Short Message Services
SNMP	Simple Network Monitoring Protocol
SNR	Signal-to-noise ratio
SO	Secondary operator
SOA	Service-oriented architecture
SON	Self-organizing networks
SONET	Synchronous Optical Networking
SP	Service providers
SPR	Subscription Profile Repository
SP-SDN	Service provider SDN
SRAM	Static random access memory
SSID	Service set identifier
SSL	Secure Sockets Layer
SSS	Standard subscriber services
STUN	Simple traversal of UDP over NAT
SUMA	Software-defined unified monitoring agent
SuVMF	Software-defined unified virtual monitoring function for SDN-based networks
TAI	Tracking area ID
TCAM	Ternary content-addressable memory
TCP	Transmission Control Protocol
TDF	Traffic Detection Function
TDM	Time-division multiplexed
TDMA	Time-division multiple access
TEID	Tunnel endpoint identifier
TFT	Traffic flow template
TLS	Transport Layer Security
ToR	The Onion Router
ToS	Theft of Service
TR	Tunnel routers

TV	Television
UDP	User Datagram Protocol
UDR	User Data Repository
UE	User equipment
UE-AMBR	UE aggregate maximum bit rate
UGC	User-generated content
UL	Uplink
UMTS	Universal Mobile Telecommunications Systems
URI	Uniform resource identifier
URL	Uniform resource locator
USIM	Universal Subscriber Identity Module
USS	User-Supportive Subsystem
VDI	Virtual desktop infrastructure
vEPC	Virtual evolved packet core
VHF	Very high frequency
VIM	Virtualized infrastructure manager
VIRMANEL	Virtual MANET Lab
VLAN	Virtual local area network
VLD	Virtual Link Descriptor
VLR	Visitor Location Register
VM	Virtual machines
VN	Virtual networks
VNE	Virtualized network element
VNF	Virtualized network function
VNFD	Virtual Network Function Descriptor
VNFD	VNF Descriptor
VNFFGD	Virtual Network Function Forwarding Graph Descriptor
VNFM	VNF manager
VNI	Visual Networking Index
VNO	Virtual network operator
VO	Virtual operator
VOD	Video on demand
VoIP	Voice over IP
VPMNO	Virtual private mobile network operator
VPN	Virtual private networks
VPNS	Virtual private network systems
VS	Virtual switches
WAP	Wireless Application Protocol
WCDMA	Wideband code division multiple access
Wi-Fi	Wireless fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless local area network
WPAN	Wireless personal area network
WWAN	Wireless wide area network
XML	Extensible Markup Language