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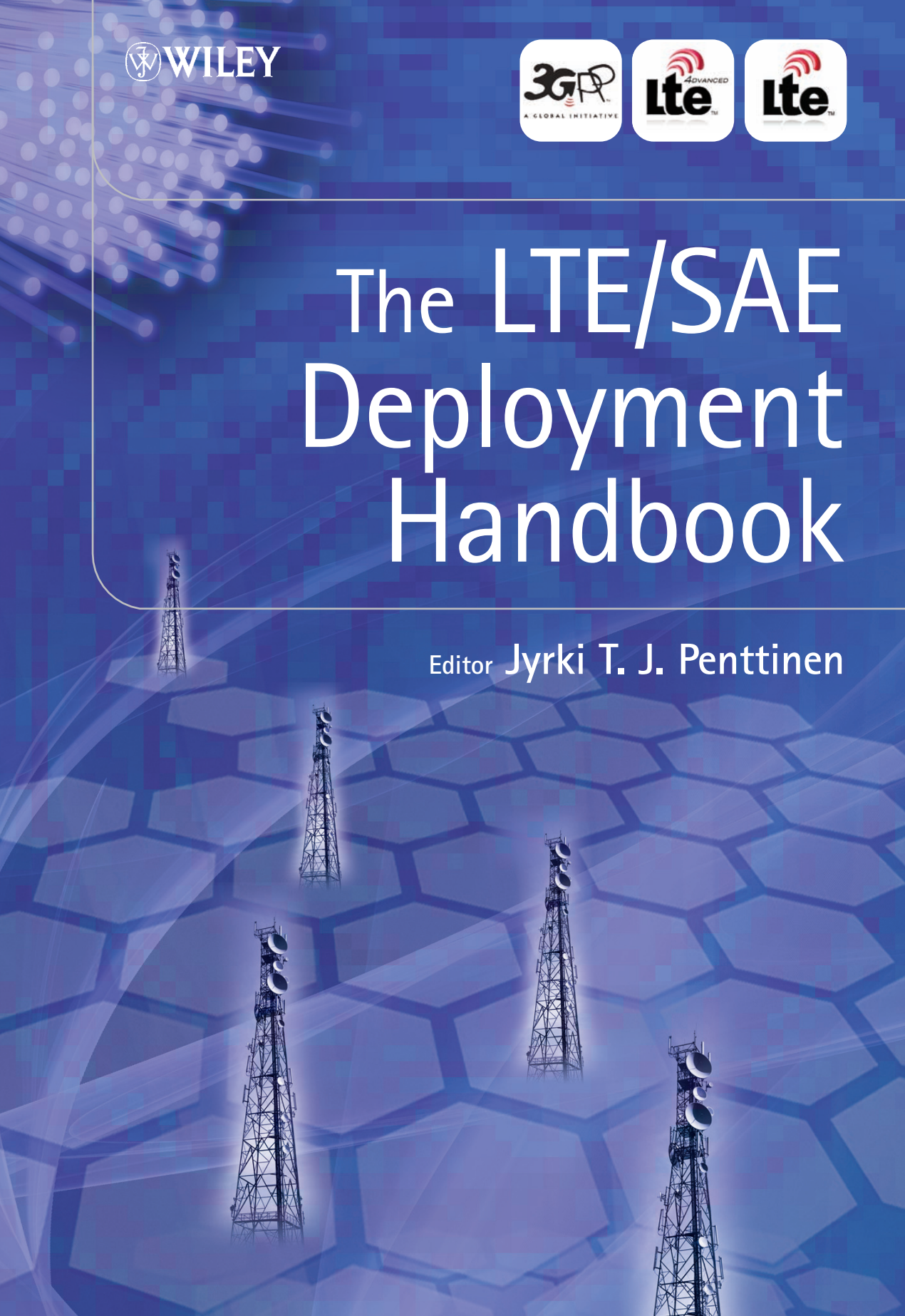

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A John Wiley & Sons, Ltd., Publication

This edition first published 2012

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

Library of Congress Cataloging-in-Publication Data

Penttinen, Jyrki T. J.
The LTE/SAE deployment handbook / Jyrki Penttinen. – 1
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-97726-2 (hardback) – ISBN 978-1-119-95417-0 (ePDF) – ISBN 978-1-119-95418-7 (oBook) – ISBN 978-1-119-96111-6 (ePub) – ISBN 978-1-119-96112-3 (mobi)
1. Long-Term Evolution (Telecommunications) 2. System Architecture Evolution (Telecommunications) I. Title.
TK5103.48325.P46 2012
621.3845′6–dc23

2011033174

A catalogue record for this book is available from the British Library.

Print ISBN: 9780470977262

Set in 10/12pt, Times Roman by Thomson Digital, Noida, India

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Foreword

Manually operated mobile communication networks were a huge success in all the Nordic countries in the 1970s but the popularity of the first-generation automatic networks (NMT) exceeded all expectations in the 1980s. It seemed impossible to estimate realistically the number of base stations needed to respond to the growing demand. Subscribers became accustomed to constantly improving service levels and coverage areas for voice calls. Gradually, during that decade, users adopted wireless voice communication and found that not only did it bring increased efficiency—it was also a highly liberating experience.

Then, along with the second generation in the 1990s (GSM), it became clear that there was a growing demand for more advanced services. International specification work on GSM formed a solid base and a favorable platform for new inventions like Short Message Service (SMS). GSM has been up and running now for more than 20 years. From the number of new innovations in 3GPP standardization it is clear that the evolution of GSM will be secure for a long time.

3G was introduced to the markets in order to provide a base for even more demanding multimedia. It provided additional capacity for voice calls as the 2G systems started to saturate. With its multiple generations and releases, the mobile telecom operators and vendors started to realize the challenges in the field as new services typically require support from both networks and terminals. On the other hand, the terminals' lifecycle is shorter because users consider them to be everyday consumer objects, and more attractive models constantly appear on the market. There is a positive balance between users, operators and equipment vendors as enhanced services typically require updates to terminals and networks.

The deployment of the packet data service as an add-on for GSM, and then its adaptation from the first phase of UMTS, were the important triggers for the use of Internet services via mobile terminals. The rapidly evolving Internet environment itself had a great impact on mobile communications, resulting in the development of multi-usage equipment for services, combining voice connections, messaging, and multimedia.

With the deployment of the third-generation networks, data rates increased in order to provide a smoother user experience. The new business environment started to strengthen. In contrast with the initial model of only few voice service providers in controlled markets, there were now increasing numbers of operators, equipment vendors, service providers, measurement equipment producers, and many other entities contributing to mobile communications. The increasing speed of standardization made development seem unlimited.

Along with the increased data rates associated with the Internet, fixed and mobile communications have also evolved steadily. Open standards, competing operators and multivendor equipment offerings have ensured that the markets developed favorably from the end user's point of view.

Evolution of 2G and 3G is gradually becoming saturated, as happened with the first-generation networks. It is easier to create a new, more efficient platform to provide the required data rate and capacity than to develop existing ones. Statistics from recent years indicate that there has been a huge growth in multimedia data transfer. The exponential growth in the use of data sets higher performance targets for the networks than ever before.

In this context, LTE has been designed as a base for a new 4G era. It paves the way towards 4G by providing a smooth transition from 2G and 3G, including important interworking functionalities as well as higher data rates and capacity than ever before in mobile network environments. In addition to 3GPP networks, LTE/SAE standardization also takes care of the evolution path from CDMA systems.

Evolving technology makes the management of mobile communications businesses more complex. Some operators can build on existing technology; others may have to start from 4G. Fixed networks must also be considered as competition for mobile networks, as their capacity, quality, and flexibility to interwork with wireless technologies increase.

At the same time, the need for relevant information is increasing. Networks are either built from scratch or through designing an evolution path from a previous system. Network planners and other technical people need to know how the systems function, how they can be planned optimally, and how to make sure that user experiences will be positive. Business managers must also understand the basic technology in order to see how they can benefit from it and what they may require from technical staff.

It is a rare to find a person who has a deep understanding of a technology and who can also write about it in an informative, simple, and understandable way. The writer of this book, Jyrki Penttinen, has this skill. This is the right book for those who wish to study LTE and the principles and details of Evolved UTRAN and Evolved Packet Core in a common-sense manner.

Matti Makkonen
CEO, Anvia Plc
Former Vice President, Sonera, Finland

Preface

Long-Term Evolution (LTE) is arguably one of the most important steps in the current phase of the development of modern mobile communications. It provides a suitable base for enhanced services due to increased data throughput and lower latency figures, and also gives extra impetus to the modernization of telecom architectures. The decision to leave the circuit-switched domain out of the scope of LTE/SAE system standardization might sound radical but it indicates that the telecom world is going strongly for the all-IP concept—and the deployment of LTE/SAE is concrete evidence of this global trend.

LTE specifications define evolved radio access for 3GPP's 3G evolution path and so they have an important influence on the core development of the new mobile network system. Along with requirements for high-speed data support for the radio network, the core network specifications have been updated to guarantee end-to-end performance. The specification work under the same 3GPP umbrella ensures that all the relevant aspects are covered in the interworking of the evolved radio and core, as well as between previous generations of 3GPP 2G and 3G networks.

There are many overlapping or similar aspects in LTE and SAE and previous 3GPP systems but the evolved network also brings plenty of novel solutions. Many performance simulations are already available, which indicates the capabilities of LTE/SAE, but the impact of the system on practical network deployment has not been particularly clear until now.

This book aims to address this growing need for information about the practical aspects of the evolved terrestrial radio access network of UMTS (E-UTRAN)—that is, LTE—as well as the evolved packet core network (EPC)—that is, System Architecture Evolution (SAE). The idea of this book is to take a step towards to the preparation of the deployment phase, presenting practical information needed in the designing and building of the LTE/SAE network. The book presents topics and examples that are helpful from the first day of the planning and deployment of LTE/SAE networks, to ensure that the initial phase provides the best possible level of service. It describes the system architecture and functionality, network planning, measurements, security, applications, and other aspects that are important in real telecommunications environments.

The book is written in a modular way. The first module consists of Chapters 1–5, which describe the background and the overall idea of the system. This part includes advice about the practical interpretation of the standards and gives the most important high-level requirements and architectural descriptions of LTE and SAE. This part is thus especially useful for anyone who lacks prior knowledge about the system.

Chapters 6–11 address more specific issues regarding the functionality of LTE/SAE and its services. This part describes the functionality and elements of the system in enough detail to

help readers to understand the technical possibilities and challenges of LTE and SAE as a part of the whole mobile communications environment.

The third module consists of Chapters 12–15, which address design-related aspects of the LTE/SAE from a practical perspective. This part contains essential guidelines for the planning, dimensioning, and measurement of LTE/SAE networks. One of the most important parts of this module, and at the same time the core of the whole book, is Chapter 15, which presents valuable recommendations for the transition from other systems to LTE. It gives various technical guidelines and examples as a basis, for example, for refarming strategies.

In general, this book can be used as a central, practical source of information in the deployment phase of LTE/SAE as well as in later phases. The book team would like to remind though that this book gives practical information about the functionality and suggestions for the network deployment, but the correctness of the contents can not be guaranteed by the team. It is encouraged to refer to the specifications and other validated information sources. The team also would like to clarify that the information and opinions presented in this book are solely of the contributors, and our employers may or may not have the same ideas.

If you have any feedback or comments about the content of the book, or suggestions about how it could be enhanced in possible future editions, please do not hesitate to contact the author directly at jyrki.penttinen@nokia.com. Additional information about LTE/SAE, based on developments in the field and feedback, may be found on the author's Internet page at www.tlt.fi.

Jyrki T. J. Penttinen

Acknowledgments

This book is the result of a joint effort by our book team. I would like to thank all the contributors for their challenging work during their spare time. I thank Nokia Siemens Networks, Nokia, TeliaSonera, Anritsu, NetHawk, Rohde & Schwarz, Samsung, and Anite for their collaboration and for providing a practical perspective for this book. Many colleagues assisted us by providing essential comments, documentation and hints. I would like to thank Dr. Harri Holma, Dr. Jorge Hermosillo, Mika Laasonen, Mikko Nurkka, Valtteri Niemi, Timo Saxen, Olli Ramula, and Antti Näykki, and all our other colleagues for their valuable support.

I give my warmest thanks to the Association of Finnish Non-Fiction Writers for their support for this project. I also thank the whole Wiley team for the guidance and professional project management.

Finally, I thank my spouse Elva and our children for their patience and support during the project.

Jyrki T. J. Penttinen

Glossary

128-QAM	128 state Quadrature Amplitude Modulation
16-QAM	16 state Quadrature Amplitude Modulation
1G	First Generation of mobile communication technologies
2G	Second Generation of mobile communication technologies
3G	Third Generation of mobile communication technologies
3GPP	3rd Generation Partnership Project
4G	Fourth Generation of mobile communication technologies
64-QAM	64 state Quadrature Amplitude Modulation
AAA	Authentication, Authorization & Accounting
ABMF	Account Balance Management Function
AC	Admission Control
ACIR	Adjacent Channel Interference Rejection
ACK	Acknowledgment
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ADC	Analogue/Digital Conversion
ADMF	Administration Function
ADSL	Asynchronous Digital Subscriber Line
AF	Africa
AF	Application Function
A-GPS	Assisted Global Positioning System
aGW	Access Gateway
AKA	Authentication and Key Agreement
AMBR	Aggregated Maximum Bit Rate
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone System
AMR	Adaptive Multi-Rate
AP	Aggregation Proxy
AP	Asia Pacific
APAC	Asia Pacific
APN	Access Point Name
APN-AMBR	APN aggregate maximum bit rate
AR	Aggregation Router
ARFCN	absolute radio-frequency channel number
ARP	Allocation Retention Priority

ARP	Automatic Radio Phone
ARPU	Average Revenue Per User
ARQ	Automatic Repeat reQuest
AS	Application Server
AS SMC	AS Security Mode Command
ATB	Adaptive Transmission Bandwidth
ATCA	Advanced Telecommunications Computing Architecture
ATM	Asynchronous Transfer Mode
AuID	Application Usage ID
AUTN	Authentication token
AVC	Advanced Video Codec
AWS	Advanced Wireless Services
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BD	Billing Domain
BE	Best Effort
BER	Bit Error Rate
BICC	Bearer Independent Call Control
BLER	Block Error Rate
BPSK	Binary Phase Shift Keying
BQS	Bad Quality Samples
BS	Base Station
BSC	Base Station Controller
BSR	Buffer Status Report
BSS	Business Support System
BTS	Base Transceiver Station
BW	Bandwidth
C/I	Carrier per Interference
CA	Certification Authority
CAMEL	Customised Applications for Mobile networks Enhanced Logic
CAPEX	Capital Expenditure
CAZAC	Constant Amplitude Zero AutoCorrelation
CC	Content of Communication
CCCH	Common Control Channel
CCN	Cell Change Notification
CCO	Cell Change Order
CDF	Charging Data Function
CDMA	Code Division Multiple Access
CDR	Call Drop Rate
CDR	Charging Data Record
CEO	Chief Executive Officer
CET	Carrier Ethernet Transport
CFB	Call Forwarding Busy
CFNRc	Call Forwarding Not Reachable
CFNRy	Call Forwarding No Reply
CFU	Call Forwarding Unconditional
CGF	Charging Gateway Function
CLIP	Calling Line Presentation

CLIR	Calling Line identity Restriction
CMAS	Commercial Mobile Alert System
CMP	Certificate Management Protocol
CN	Core Network
COLP	Connected Line Presentation
COLR	Connected Line identity Restriction
CoMP	Coordinated multipoint
CP	Cyclic Prefix
CPICH	Common Pilot Channel
CPM	Converged IP Messaging
CQI	Channel Quality Indicator
CR	Carriage Return
CRC	Cyclic Redundancy Check
CS	Circuit Switched
CSFB	Circuit Switched Fall Back
CSI	Channel State Information
CT	Core Network and Terminals (TSG)
CTF	Charging Trigger Function
CTM	Cellular Text Telephony Modem
DAB	Digital Audio Broadcasting
DCCA	Diameter Credit Control Application
DCCH	Dedicated Control Channel
DD	Digital Dividend
DFCA	Dynamic Frequency and Channel Allocation
DFT	Discrete Fourier Transform
DFTS-OFDM	Discrete Fourier Transform Spread-OFDM
DHCP	Dynamic Host Configuration Protocol
DHR	Dual Half Rate (voice codec)
DL	Downlink
DLDC	Downlink Dual Carrier
DL-SCH	Downlink Shared Channel
DMR	Digital Mobile Radio
DoS	Denial of Service
DPI	Deep Packet Inspection
DRB	Data Radio Bearer
DRX	Discontinuous Reception
DSCP	DiffServ Code Point
DSL	Digital Subscriber Line
DSMIPv6	Dual-Stack Mobile IPv6
DTCH	Dedicated Traffic Channel
DTM	Dual Transfer Mode
DTMF	Dual Tone Multi-Frequency
DTX	Discontinuous Transmission
DUT	Device Under Test
DVB-H	Digital Video Broadcasting, Handheld
DVB-T	Digital Video Broadcasting, Terrestrial
ECM	EPS Connection Management
E-CSCF	Emergency Call State Control Function

EDGE	Enhanced Data Rates for Global Evolution
EF	Expedited Forwarding
EFL	Effective Frequency Load
E-GPRS	Enhanced GPRS
EHPLMN	Equivalent HPLMN
eHRPD	Evolved High Rate Packet Data
EMM	EPS Mobility Management
EMR	Enhanced Measurement Reporting
eNB	Evolved Node B
ENUM	E.164 Number Mapping
EPC	Evolved Packet Core
ePDG	Evolved Packet Data Gateway
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
ETWS	Earthquake and Tsunami Warning System
EU	European Union
E-UTRAN	Evolved UMTS Radio Access Network
EV-DO	Evolution-Data Only
EVM	Error Vector Magnitude
FACCH	Fast Associated Control Channel
FCC	US Federal Communications Commission
FCCH	Frequency Correction Channel
FDD	Frequency Division Duplex
FDPS	Frequency-Domain Packet Scheduling
FER	Frame Erasure Rate
FFS	For Further Study
FFT	Fast Fourier Transform
FH	Frequency Hopping
FMC	Fixed Mobile Convergence
FNO	Fixed Network Operator
FPLMTS	Future Public Land Mobile Telecommunications System
FR	Frame Relay
FR	Full Rate (voice codec)
FR-AMR	AMR Full Rate
GAA	Generic Authentication Algorithm
GAN	Generic Access Network
GBR	Guaranteed Bit Rate
GCF	Global Certification Forum
GERAN	GSM EDGE Radio Access Network (TSG)
GGSN	GPRS Gateway Support Node
GMLC	Gateway Mobile Location Centre
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GRE	Generic Routing Encapsulation
GRX	GPRS Roaming Exchange
GSM	Global System for Mobile communications
GSMA	GSM Association
GTP	GPRS Tunnelling Protocol

GTT	Global Text Telephony
GTT-CS	Global Text Telephony over video telephony
GTTP	GPRS Transparent Transport Protocol
GTT-Voice	Global Text Telephony over voice
GW	Gateway
HARQ	Hybrid Automatic Retransmission on request/Hybrid Automatic Repeat Request
HD	High Definition
HDSL	High-bit-rate Digital Subscriber Line
HeNB GW	Home eNB Gateway
HeNB	Home eNB
HLR	Home Location Register
HO	Handover
hPCRF	Home Policy and Charging Rules Function
HPLMN	Home PLMN
HR	Half Rate (voice codec)
HR-AMR	AMR Half Rate
HRPD	High Rate Packet Data
HSCSD	High Speed Circuit Switched Data
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
IBCF	Interconnection Border Control Functions
ICE	Intercepting Control Element
ICI	Inter-Carrier Interference
ICIC	Inter Cell Interference Control
ICS	IMS Centralized Services
I-CSCF	Interrogating Call State Control Function
IDFT	Inverse Discrete Fourier Transform
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
I-HSPA	Internet HSPA
IMEI	International Mobile Equipment Identity
IMS	IP Multimedia Sub-system
IMSI	International Mobile Subscriber Identity
IMS-MGW	IMS-Media Gateway
IMS-NNI	IMS Network-Network Interface
IM-SSF	IP Multimedia – Service Switching Function
IMT-2000	International Mobile Telecommunication requirements (ITU)
IMT-Advanced	Advanced International Mobile Telecommunication requirements (ITU)
IN	Intelligent Network
INAP	Intelligent Network Application Protocol
IOT	Inter-Operability Testing
IP	Internet Protocol
IPsec	IP Security

IP-SM-GW	IP-Short Message-Gateway
IPv4	IP version 4
IPv6	IP version 6
IPX	IP eXchange
IQ	In-phase (I) and out of phase (Q) components of modulation
IRI	Intercept Related Information
ISC	IMS Service Control
ISI	Inter-Symbol Interference
ISIM	IMS Subscriber Identity Module
ISR	Idle Mode Signaling Reduction
ISUP	ISDN User Part
ITU	International Telecommunication Union
ITU-R	ITU's Radiocommunication Sector
ITU-T	ITU's Telecommunication sector
IWF	Interworking Function
JSLEE	JAIN Service Logic Execution Environments
KDF	Key Derivation Function
KPI	Key Performance Indicator
LA	Latin America
LA	Link Adaptation
LA	Location Area
LAU	Location Area Update
LBO	Local Breakout
LCS	Location Service
LEA	Law Enforcement Agencies
LEMF	Law Enforcement Monitoring Facilities
LI	Lawful Interception
LIG	Legal Interception Gateway
LRF	Location Retrieval Function
LSP	Label Switch Path
LTE	Long Term Evolution
LTE-A	LTE-Advanced
LTE-UE	LTE User Equipment
MA	Mobile Allocation
MAC	Medium Access Control
MAIO	Mobile Allocation Index Offset
MAN	Metropolitan Area Network
MBMS	Multimedia Broadcast Multicast Service
MBR	Maximum Bit Rate
MCC	Mobile Country Code
MCCH	Multicast Control Channel
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MC-TD-SCDMA	Multi-Carrier Time-Division Synchronous-Code-Division Multiple Access
MC-WCDMA	Multi-Carrier Wide-band Code-Division Multiple Access
ME id	Mobile Equipment Identifier
ME	Middle East