

 WILEY



The LTE/SAE Deployment Handbook

Editor Jyrki T. J. Penttinen



THE LTE/SAE DEPLOYMENT HANDBOOK

THE LTE/SAE DEPLOYMENT HANDBOOK

Edited by

Jyrki T. J. Penttinen

Nokia Siemens Networks Innovation Center (NICE), Spain

 **WILEY**

A John Wiley & Sons, Ltd., Publication

This edition first published 2012
© 2012 John Wiley & Sons, Ltd

Registered office

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

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

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

Contents

List of Contributors	xv
Foreword	xvii
Preface	xix
Acknowledgments	xxi
Glossary	xxiii
1 General	1
1.1 Introduction	1
1.2 The LTE Scene	1
1.3 The Role of LTE in Mobile Communications	2
1.4 LTE/SAE Deployment Process	3
1.5 The Contents of the Book	7
References	9
2 Drivers for LTE/SAE	11
2.1 Introduction	11
2.2 Mobile System Generations	11
2.3 Data Service Evolution	14
2.3.1 <i>Development up to 3G</i>	14
2.3.2 <i>Demand for Multimedia</i>	14
2.3.3 <i>Commercial LTE Deployments</i>	17
2.3.4 <i>LTE Refarming Eases Development</i>	17
2.4 Reasons for the Deployment of LTE	19
2.4.1 <i>General</i>	19
2.4.2 <i>Relationship with Alternative Models</i>	19
2.4.3 <i>TD-LTE versus FD-LTE</i>	20
2.5 Next Steps of LTE/SAE	20
2.6 Summary of the Benefits of LTE	21
References	21
3 LTE/SAE Overview	23
3.1 Introduction	23
3.2 LTE/SAE Standards	24
3.3 How to Find Information from Specs?	25

3.4	Evolution Path Towards LTE	27
3.5	Key Parameters of LTE	28
3.6	LTE vs WiMAX	29
3.7	Models for Roaming Architecture	29
3.7.1	<i>Roaming Functionality</i>	29
3.7.2	<i>Operator Challenges</i>	29
3.7.3	<i>CS Fallback</i>	30
3.7.4	<i>Inter-Operator Security Aspects</i>	32
3.7.5	<i>Selection of Voice Service Method</i>	32
3.7.6	<i>Roaming and Interconnection Aspects of LTE/SAE</i>	34
3.8	LTE/SAE Services	36
3.8.1	<i>Data</i>	36
3.8.2	<i>Voice</i>	39
3.8.3	<i>MBMS</i>	39
3.9	LTE-Advanced—Next Generation LTE	40
3.9.1	<i>Key Aspects of LTE-Advanced</i>	40
3.9.2	<i>Comparison of 3G and 4G</i>	41
3.9.3	<i>Enablers for the LTE-Advanced Performance</i>	41
	References	42
4	Performance Requirements	45
4.1	Introduction	45
4.2	LTE Key Features	45
4.2.1	<i>Release 8</i>	45
4.2.2	<i>Release 9</i>	46
4.2.3	<i>Release 10</i>	46
4.3	Standards LTE Requirements	49
4.3.1	<i>Early Ideas of LTE</i>	49
4.3.2	<i>Standard Radio Requirements of LTE</i>	50
4.3.3	<i>Data Performance</i>	55
4.3.4	<i>LTE-UE Requirements</i>	55
4.3.5	<i>Delay Requirements for Backhaul</i>	56
4.3.6	<i>System Architecture Evolution</i>	58
4.4	Effects of the Requirements on the LTE/SAE Network Deployment	60
4.4.1	<i>Evolved Environment</i>	60
4.4.2	<i>Spectral Efficiency</i>	61
	References	62
5	LTE and SAE Architecture	63
5.1	Introduction	63
5.2	Elements	63
5.2.1	<i>eNodeB</i>	65
5.2.2	<i>S-GW</i>	68
5.2.3	<i>P-GW</i>	68
5.2.4	<i>MME</i>	68
5.2.5	<i>GSM and UMTS Domain</i>	69
5.2.6	<i>Packet Data Network</i>	70

5.3	Interfaces	70
5.3.1	<i>Uu Interface</i>	70
5.3.2	<i>X2 Interface</i>	70
5.3.3	<i>S1 Interface</i>	70
5.3.4	<i>S3 Interface</i>	70
5.3.5	<i>S4 Interface</i>	70
5.3.6	<i>S5 Interface</i>	70
5.3.7	<i>S6a Interface</i>	71
5.3.8	<i>S11 Interface</i>	71
5.3.9	<i>SGi</i>	71
5.3.10	<i>Gn/Gp</i>	71
5.4	Protocol Stacks	71
5.4.1	<i>User Plane</i>	71
5.4.2	<i>Control Plane</i>	73
5.4.3	<i>Layer 1</i>	73
5.4.4	<i>Layer 2</i>	74
5.4.5	<i>Layer 3</i>	75
5.5	Layer 2 Structure	75
	References	77
6	Transport and Core Network	79
6.1	Introduction	79
6.2	Functionality of Transport Elements	79
6.2.1	<i>Transport Modules</i>	79
6.2.2	<i>LTE Transport Protocol Stack</i>	80
6.2.3	<i>Ethernet Transport</i>	80
6.2.4	<i>IP Address Differentiation</i>	81
6.2.5	<i>Traffic Prioritization on the IP Layer</i>	81
6.2.6	<i>Traffic Prioritization on Ethernet Layer</i>	81
6.2.7	<i>VLAN Based Traffic Differentiation</i>	81
6.2.8	<i>IPsec</i>	81
6.2.9	<i>Synchronization</i>	82
6.2.10	<i>Timing Over Packet</i>	82
6.2.11	<i>Synchronous Ethernet</i>	83
6.3	Transport Network	83
6.3.1	<i>Carrier Ethernet Transport</i>	83
6.3.2	<i>Transport for S1-U Interface</i>	84
6.4	Core Network	85
6.5	IP Multimedia Subsystem	86
6.5.1	<i>IMS Architecture</i>	86
	References	93
7	LTE Radio Network	95
7.1	Introduction	95
7.2	LTE Radio Interface	95
7.3	LTE Spectrum	96
7.4	OFDM and OFDMA	96
7.4.1	<i>General Principle</i>	96

7.4.2	<i>OFDM Transceiver Chain</i>	100
7.4.3	<i>Cyclic Prefix</i>	101
7.4.4	<i>Channel Estimation and Equalization</i>	102
7.4.5	<i>Modulation</i>	104
7.4.6	<i>Coding</i>	106
7.4.7	<i>Signal Processing Chain</i>	106
7.5	SC-FDM and SC-FDMA	107
7.5.1	<i>SC-FDM Transceiver Chain</i>	108
7.5.2	<i>PAPR Benefits</i>	108
7.6	Reporting	108
7.6.1	<i>CSI</i>	108
7.6.2	<i>CQI</i>	109
7.6.3	<i>RI</i>	110
7.6.4	<i>PMI</i>	111
7.7	LTE Radio Resource Management	111
7.7.1	<i>Introduction</i>	111
7.7.2	<i>QoS and Associated Parameters</i>	112
7.8	RRM Principles and Algorithms Common to UL and DL	113
7.8.1	<i>Connection Mobility Control</i>	113
7.8.2	<i>Admission Control</i>	116
7.8.3	<i>HARQ</i>	117
7.8.4	<i>Link Adaptation</i>	117
7.8.5	<i>Packet Scheduling</i>	118
7.8.6	<i>Load Balancing</i>	122
7.9	Uplink RRM	123
7.9.1	<i>Packet Scheduling: Specific UL Constraints</i>	123
7.9.2	<i>Link Adaptation</i>	124
7.9.3	<i>Uplink Signaling for Scheduling and Link Adaptation Support</i>	126
7.10	Downlink RRM	128
7.10.1	<i>Channel Quality, Feedback and Link Adaptation</i>	129
7.10.2	<i>Packet Scheduling</i>	130
7.10.3	<i>Inter Cell Interference Control</i>	131
7.11	Intra-LTE Handover	132
	References	134
8	Terminals and Applications	137
8.1	Introduction	137
8.2	Effect of Smartphones on LTE	137
8.2.1	<i>General</i>	137
8.2.2	<i>Is LTE Capable Enough to Handle the Challenge?</i>	138
8.2.3	<i>LTE RRC States</i>	139
8.3	Interworking	139
8.3.1	<i>Simultaneous Support for LTE/SAE and 2G/3G</i>	139
8.3.2	<i>Support for CS Fallback and VoLTE</i>	141
8.4	LTE Terminal Requirements	143
8.4.1	<i>Performance</i>	143
8.4.2	<i>LTE-UE Categories</i>	144

8.4.3	<i>HW Architecture</i>	144
8.4.4	<i>Conformance Test Aspects</i>	148
8.5	LTE Applications	149
8.5.1	<i>Non-Operator Applications</i>	149
8.5.2	<i>Rich Communication Suite</i>	151
8.5.3	<i>LTE/SAE and RCS</i>	154
	References	155
9	Voice Over LTE	157
9.1	Introduction	157
9.2	CS Fallback for Evolved Packet System	158
9.3	SMS Over SGs	159
9.3.1	<i>Functionality</i>	160
9.3.2	<i>Combined EPS/IMSI Attachment</i>	160
9.3.3	<i>Mobile Originated Short Message</i>	161
9.3.4	<i>Mobile Terminating Short Message</i>	162
9.3.5	<i>Deployment View</i>	163
9.4	Voice and Other CS Services than SMS	164
9.4.1	<i>Voice and Video Call</i>	165
9.4.2	<i>Call Unrelated to Supplementary and Location Services</i>	166
9.4.3	<i>Deployment View</i>	169
9.5	Voice and SMS Over IP	169
9.5.1	<i>IP Multimedia Subsystem</i>	170
9.5.2	<i>Voice and Video Telephony Over IP</i>	171
9.6	Summary	186
	References	187
10	Functionality of LTE/SAE	189
10.1	Introduction	189
10.2	States	189
10.2.1	<i>Mobility Management</i>	190
10.2.2	<i>Handover</i>	191
10.2.3	<i>Connection Management</i>	191
10.2.4	<i>Authentication</i>	196
10.2.5	<i>Tracking Area</i>	196
10.2.6	<i>Paging Procedure</i>	198
10.3	End-to-End Functionality	199
10.4	LTE/SAE Roaming	200
10.4.1	<i>General</i>	200
10.4.2	<i>Roaming Architecture</i>	201
10.4.3	<i>Inter-Operator Connectivity</i>	203
10.4.4	<i>Home Routing</i>	205
10.4.5	<i>Local Breakout</i>	206
10.4.6	<i>Home Routing versus Local Breakout</i>	208
10.4.7	<i>Other Features</i>	210
10.4.8	<i>APN Usage</i>	211
10.4.9	<i>Service-Specific Aspects</i>	212

10.5	Charging	216
	10.5.1 Offline Charging	217
	10.5.2 Charging Data Record	218
	10.5.3 Online Charging	218
	References	219
11	LTE/SAE Security	221
11.1	Introduction	221
11.2	LTE Security Risk Identification	222
	11.2.1 Security Process	222
	11.2.2 Network Attack Types in LTE/SAE	222
	11.2.3 Preparation for Attacks	224
	11.2.4 Certificates	224
	11.2.5 LTE Transport Security	227
	11.2.6 Traffic Filtering	228
	11.2.7 Radio Interface Security	229
11.3	LTE/SAE Service Security—Case Example	234
	11.3.1 General	234
	11.3.2 IPSec	234
	11.3.3 IPSec Processing and Security Gateway	235
	11.3.4 Single Tunnel with Dedicated Tunnel Interfaces	237
	11.3.5 Single Tunnel with Shared Tunnel Interfaces	237
	11.3.6 Multiple Tunnels with Dedicated Tunnel Interfaces	237
	11.3.7 Multiple Tunnels with Shared Tunnel Interfaces	237
	11.3.8 Summary	238
11.4	Authentication and Authorization	238
11.5	Customer Data Safety	239
11.6	Lawful Interception	239
	References	242
12	Planning and Deployment of SAE	243
12.1	Introduction	243
12.2	Network Evolution from 2G/3G PS Core to EPC	243
	12.2.1 3GPP R8 Requirements for LTE Support in Packet Core Network	243
	12.2.2 Introducing LTE in Operator Network	244
12.3	Entering Commercial Phase: Support for Multi-Mode LTE/3G/2G Terminals with Pre-Release 8 SGSN	245
	12.3.1 Support for Multi-Mode LTE/3G/2G Terminals with Release 8 Network	245
	12.3.2 Optimal Solution for 2G/3G SGSN and MME from Architecture Point of View	246
12.4	SGSN/MME Evolution	248
	12.4.1 Requirements to MME Functionality in LTE Networks	248
12.5	Case Example: Commercial SGSN/MME Offering	249
	12.5.1 Nokia Siemens Networks Flexi Network Server	249
	12.5.2 Aspects to Consider in SGSN/MME Evolution Planning	250

12.6	Mobile Gateway Evolution	250
12.6.1	<i>Requirements to Mobile Gateway in Mobile Broadband Networks</i>	250
12.7	Case Example: Commercial GGSN/S-GW/P-GW Offering	251
12.7.1	<i>Nokia Siemens Networks Flexi Network Gateway</i>	251
12.7.2	<i>Aspects to Consider in GGSN/S-GW/P-GW Evolution Planning</i>	252
12.8	EPC Network Deployment and Topology Considerations	252
12.8.1	<i>EPC Topology Options</i>	252
12.8.2	<i>EPC Topology Evolution</i>	253
12.9	LTE Access Dimensioning	254
13	Radio Network Planning	257
13.1	Introduction	257
13.2	Radio Network Planning Process	257
13.3	Nominal Network Planning	260
13.3.1	<i>Quality of Service</i>	261
13.4	Capacity Planning	263
13.5	Coverage Planning	264
13.5.1	<i>Radio Link Budget</i>	265
13.5.2	<i>Radio Propagation Models</i>	269
13.5.3	<i>Frequency Planning</i>	270
13.5.4	<i>Other Planning Aspects</i>	271
13.6	Self-Optimizing Network	271
	Reference	272
14	LTE/SAE Measurements	273
14.1	Introduction	273
14.2	General	273
14.2.1	<i>Measurement Points</i>	273
14.3	Principles of Radio Interface Measurements	273
14.3.1	<i>LTE Specific Issues for the Measurements</i>	274
14.3.2	<i>LTE Traffic Simulators</i>	276
14.3.3	<i>Typical LTE Measurements</i>	278
14.3.4	<i>Type Approval Measurements</i>	280
14.3.5	<i>Modulation Error Measurements</i>	281
14.3.6	<i>LTE Performance Simulations</i>	281
14.4	LTE Field Measurements	282
14.4.1	<i>Typical Field Test Environment</i>	283
14.4.2	<i>Test Network Setup</i>	284
14.4.3	<i>Test Case Selection</i>	288
14.4.4	<i>Items to Assure</i>	289
14.5	Evolution Changes the Rules of Testing	289
14.6	General Test Requirements and Methods for the LTE Air Interface	292
14.6.1	<i>OFDM Radio Testing</i>	292
14.6.2	<i>MIMO Testing</i>	294
14.6.3	<i>LI Testing</i>	296

14.6.4	<i>L2/L3 Testing in LTE</i>	297
14.6.5	<i>UE Test Loop Modes</i>	297
14.7	Test Requirements in SAE	298
14.7.1	<i>Testing at the Network Service Level</i>	299
14.8	Throughput Testing	300
14.8.1	<i>End-to-End Network Innovation</i>	301
14.8.2	<i>Base Station Scheduler as Key Controller of Radio Resources</i>	301
14.8.3	<i>L1 Performance vs. L3/PDCP Throughput</i>	302
14.8.4	<i>OTA (Over The Air) Testing</i>	304
14.8.5	<i>Summary</i>	305
14.9	Self-Organizing Network Techniques for Test and Measurement	306
14.9.1	<i>SON Definition and Basic Principles</i>	306
14.9.2	<i>Technical Issues and Impact on Network Planning</i>	307
14.9.3	<i>Effects on Network Installation, Commissioning and Optimization Strategies</i>	308
14.9.4	<i>Conclusion</i>	309
14.10	Field Testing	309
14.10.1	<i>LTE Coverage and Power Quality Measurements</i>	311
14.10.2	<i>Guidelines for LTE Measurements</i>	317
	References	323
15	Recommendations	325
15.1	Introduction	325
15.2	Transition to LTE—Use Cases	326
15.2.1	<i>Total Swap</i>	326
15.2.2	<i>Hot Spots</i>	326
15.3	Spectrum Aspects	327
15.3.1	<i>General View on Spectrum Allocation</i>	327
15.3.2	<i>Coexistence with GSM</i>	335
15.4	Effect of the Advanced GSM Features on the Fluent LTE Deployment	343
15.4.1	<i>Common BCCH</i>	344
15.4.2	<i>AMR Full and Half Rate</i>	347
15.4.3	<i>Single Antenna Interference Cancellation</i>	349
15.4.4	<i>Orthogonal Subchannel</i>	350
15.4.5	<i>Antenna Hopping</i>	354
15.4.6	<i>EGPRS2 and Downlink Dual Carrier</i>	357
15.4.7	<i>Dynamic Frequency and Channel Allocation</i>	359
15.4.8	<i>Signaling Improvements</i>	364
15.5	Alternative Network Migration Path (Multi-Operator Case)	367
15.5.1	<i>Introduction to Network Sharing Variants</i>	368
15.5.2	<i>MORAN and MOBSS</i>	369
15.5.3	<i>MOCN</i>	371
15.5.4	<i>National Roaming, Geographical Roaming and IMSI Based Handover</i>	374
15.6	Hardware Migration Path	376
15.6.1	<i>Colocated Antenna Systems</i>	377
15.6.2	<i>Colocation with Shared Multi-Radio Base Station</i>	380

15.7	Mobile Backhaul—Towards “All-IP” Transport	381
	15.7.1 <i>Motivation to IP Evolution in Mobile Backhaul</i>	381
	15.7.2 <i>Transport Aspects in Packet Backhaul</i>	383
15.8	LTE Interworking with Legacy Networks for the Optimal Voice and Data Services	384
	15.8.1 <i>Intersystem Mobility Management for Data Services</i>	385
	15.8.2 <i>CS Fallback</i>	394
	15.8.3 <i>Idle Mode Signaling Reduction</i>	404
	References	405
	Index	407

List of Contributors

Mohammad Anas
Adnan Basir
Jonathan Borrill
Francesco D. Calabrese
Luca Fauro
Marcin Grygiel
Jukka Hongisto
Tero Jalkanen
Juha Kallio
Krystian Krysmalski
Sebastian Lasek
Grzegorz Lehmann
Luis Maestro
Krystian Majchrowicz
Guillaume Monghal
Maciej Pakulski
Jyrki T. J. Penttinen
Olli Ramula
Dariusz Tomeczko

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 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 Hermsillo, Mika Laasonen, Mikko Nurkka, Valteri 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
ACL	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ADC	Analogue/Digital Conversion
ADM	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
GTPP	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