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 Development up to 3G 14
    2.3.2 Demand for Multimedia 14
    2.3.3 Commercial LTE Deployments 17
    2.3.4 LTE Refarming Eases Development 17
  2.4 Reasons for the Deployment of LTE 19
    2.4.1 General 19
    2.4.2 Relationship with Alternative Models 19
    2.4.3 TD-LTE versus FD-LTE 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

### 3.5 Key Parameters of LTE

### 3.6 LTE vs WiMAX

### 3.7 Models for Roaming Architecture

#### 3.7.1 Roaming Functionality

#### 3.7.2 Operator Challenges

#### 3.7.3 CS Fallback

#### 3.7.4 Inter-Operator Security Aspects

#### 3.7.5 Selection of Voice Service Method

#### 3.7.6 Roaming and Interconnection Aspects of LTE/SAE

### 3.8 LTE/SAE Services

#### 3.8.1 Data

#### 3.8.2 Voice

#### 3.8.3 MBMS

### 3.9 LTE-Advanced—Next Generation LTE

#### 3.9.1 Key Aspects of LTE-Advanced

#### 3.9.2 Comparison of 3G and 4G

#### 3.9.3 Enablers for the LTE-Advanced Performance

### References

### 4 Performance Requirements

#### 4.1 Introduction

#### 4.2 LTE Key Features

##### 4.2.1 Release 8

##### 4.2.2 Release 9

##### 4.2.3 Release 10

#### 4.3 Standards LTE Requirements

##### 4.3.1 Early Ideas of LTE

##### 4.3.2 Standard Radio Requirements of LTE

##### 4.3.3 Data Performance

##### 4.3.4 LTE-UE Requirements

##### 4.3.5 Delay Requirements for Backhaul

##### 4.3.6 System Architecture Evolution

#### 4.4 Effects of the Requirements on the LTE/SAE Network Deployment

##### 4.4.1 Evolved Environment

##### 4.4.2 Spectral Efficiency

### References

### 5 LTE and SAE Architecture

#### 5.1 Introduction

#### 5.2 Elements

##### 5.2.1 eNodeB

##### 5.2.2 S-GW

##### 5.2.3 P-GW

##### 5.2.4 MME

##### 5.2.5 GSM and UMTS Domain

##### 5.2.6 Packet Data Network

### References
6 Transport and Core Network

6.1 Introduction 79
6.2 Functionality of Transport Elements 79
   6.2.1 Transport Modules 79
   6.2.2 LTE Transport Protocol Stack 80
   6.2.3 Ethernet Transport 80
   6.2.4 IP Address Differentiation 81
   6.2.5 Traffic Prioritization on the IP Layer 81
   6.2.6 Traffic Prioritization on Ethernet Layer 81
   6.2.7 VLAN Based Traffic Differentiation 81
   6.2.8 IPsec 81
   6.2.9 Synchronization 82
   6.2.10 Timing Over Packet 82
   6.2.11 Synchronous Ethernet 83
6.3 Transport Network 83
   6.3.1 Carrier Ethernet Transport 83
   6.3.2 Transport for S1-U Interface 84
6.4 Core Network 85
6.5 IP Multimedia Subsystem 86
   6.5.1 IMS Architecture 86
References 93

7 LTE Radio Network

7.1 Introduction 95
7.2 LTE Radio Interface 95
7.3 LTE Spectrum 96
7.4 OFDM and OFDMA 96
   7.4.1 General Principle 96
7.4.2 OFDM Transceiver Chain 100
7.4.3 Cyclic Prefix 101
7.4.4 Channel Estimation and Equalization 102
7.4.5 Modulation 104
7.4.6 Coding 106
7.4.7 Signal Processing Chain 106
7.5 SC-FDM and SC-FDMA 107
7.5.1 SC-FDM Transceiver Chain 108
7.5.2 PAPR Benefits 108
7.6 Reporting 108
7.6.1 CSI 108
7.6.2 CQI 109
7.6.3 RI 110
7.6.4 PMI 111
7.7 LTE Radio Resource Management 111
7.7.1 Introduction 111
7.7.2 QoS and Associated Parameters 112
7.8 RRM Principles and Algorithms Common to UL and DL 113
7.8.1 Connection Mobility Control 113
7.8.2 Admission Control 116
7.8.3 HARQ 117
7.8.4 Link Adaptation 117
7.8.5 Packet Scheduling 118
7.8.6 Load Balancing 122
7.9 Uplink RRM 123
7.9.1 Packet Scheduling: Specific UL Constraints 123
7.9.2 Link Adaptation 124
7.9.3 Uplink Signaling for Scheduling and Link Adaptation Support 126
7.10 Downlink RRM 128
7.10.1 Channel Quality, Feedback and Link Adaptation 129
7.10.2 Packet Scheduling 130
7.10.3 Inter Cell Interference Control 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 General 137
8.2.2 Is LTE Capable Enough to Handle the Challenge? 138
8.2.3 LTE RRC States 139
8.3 Interworking 139
8.3.1 Simultaneous Support for LTE/SAE and 2G/3G 139
8.3.2 Support for CS Fallback and VoLTE 141
8.4 LTE Terminal Requirements 143
8.4.1 Performance 143
8.4.2 LTE-UE Categories 144
9 Voice Over LTE
9.1 Introduction 157
9.2 CS Fallback for Evolved Packet System 158
9.3 SMS Over SGs 159
  9.3.1 Functionality 160
  9.3.2 Combined EPS/IMSI Attachment 160
  9.3.3 Mobile Originated Short Message 161
  9.3.4 Mobile Terminating Short Message 162
  9.3.5 Deployment View 163
9.4 Voice and Other CS Services than SMS 164
  9.4.1 Voice and Video Call 165
  9.4.2 Call Unrelated to Supplementary and Location Services 166
  9.4.3 Deployment View 169
9.5 Voice and SMS Over IP 169
  9.5.1 IP Multimedia Subsystem 170
  9.5.2 Voice and Video Telephony Over IP 171
9.6 Summary 186
References 187

10 Functionality of LTE/SAE
10.1 Introduction 189
10.2 States 189
  10.2.1 Mobility Management 190
  10.2.2 Handover 191
  10.2.3 Connection Management 191
  10.2.4 Authentication 196
  10.2.5 Tracking Area 196
  10.2.6 Paging Procedure 198
10.3 End-to-End Functionality 199
10.4 LTE/SAE Roaming 200
  10.4.1 General 200
  10.4.2 Roaming Architecture 201
  10.4.3 Inter-Operator Connectivity 203
  10.4.4 Home Routing 205
  10.4.5 Local Breakout 206
  10.4.6 Home Routing versus Local Breakout 208
  10.4.7 Other Features 210
  10.4.8 APN Usage 211
  10.4.9 Service-Specific Aspects 212
10.5 Charging
   10.5.1 Offline Charging
   10.5.2 Charging Data Record
   10.5.3 Online Charging

References

11 LTE/SAE Security

11.1 Introduction

11.2 LTE Security Risk Identification
   11.2.1 Security Process
   11.2.2 Network Attack Types in LTE/SAE
   11.2.3 Preparation for Attacks
   11.2.4 Certificates
   11.2.5 LTE Transport Security
   11.2.6 Traffic Filtering
   11.2.7 Radio Interface Security

11.3 LTE/SAE Service Security—Case Example
   11.3.1 General
   11.3.2 IPSec
   11.3.3 IPSec Processing and Security Gateway
   11.3.4 Single Tunnel with Dedicated Tunnel Interfaces
   11.3.5 Single Tunnel with Shared Tunnel Interfaces
   11.3.6 Multiple Tunnels with Dedicated Tunnel Interfaces
   11.3.7 Multiple Tunnels with Shared Tunnel Interfaces
   11.3.8 Summary

11.4 Authentication and Authorization

11.5 Customer Data Safety

11.6 Lawful Interception

References

12 Planning and Deployment of SAE

12.1 Introduction

12.2 Network Evolution from 2G/3G PS Core to EPC
   12.2.1 3GPP R8 Requirements for LTE Support in Packet
           Core Network
   12.2.2 Introducing LTE in Operator Network

12.3 Entering Commercial Phase: Support for Multi-Mode
   LTE/3G/2G Terminals with Pre-Release 8 SGSN
   12.3.1 Support for Multi-Mode LTE/3G/2G Terminals with
           Release 8 Network
   12.3.2 Optimal Solution for 2G/3G SGSN and MME from
           Architecture Point of View

12.4 SGSN/MME Evolution
   12.4.1 Requirements to MME Functionality in LTE Networks

12.5 Case Example: Commercial SGSN/MME Offering
   12.5.1 Nokia Siemens Networks Flexi Network Server
   12.5.2 Aspects to Consider in SGSN/MME Evolution Planning
12.6 Mobile Gateway Evolution
12.6.1 Requirements to Mobile Gateway in Mobile Broadband Networks
12.7 Case Example: Commercial GGSN/S-GW/P-GW Offering
12.7.1 Nokia Siemens Networks Flexi Network Gateway
12.7.2 Aspects to Consider in GGSN/S-GW/P-GW Evolution Planning
12.8 EPC Network Deployment and Topology Considerations
12.8.1 EPC Topology Options
12.8.2 EPC Topology Evolution
12.9 LTE Access Dimensioning

13 Radio Network Planning
13.1 Introduction
13.2 Radio Network Planning Process
13.3 Nominal Network Planning
13.3.1 Quality of Service
13.4 Capacity Planning
13.5 Coverage Planning
13.5.1 Radio Link Budget
13.5.2 Radio Propagation Models
13.5.3 Frequency Planning
13.5.4 Other Planning Aspects
13.6 Self-Optimizing Network

Reference

14 LTE/SAE Measurements
14.1 Introduction
14.2 General
14.2.1 Measurement Points
14.3 Principles of Radio Interface Measurements
14.3.1 LTE Specific Issues for the Measurements
14.3.2 LTE Traffic Simulators
14.3.3 Typical LTE Measurements
14.3.4 Type Approval Measurements
14.3.5 Modulation Error Measurements
14.3.6 LTE Performance Simulations
14.4 LTE Field Measurements
14.4.1 Typical Field Test Environment
14.4.2 Test Network Setup
14.4.3 Test Case Selection
14.4.4 Items to Assure
14.5 Evolution Changes the Rules of Testing
14.6 General Test Requirements and Methods for the LTE Air Interface
14.6.1 OFDM Radio Testing
14.6.2 MIMO Testing
14.6.3 LI Testing
14.6.4 L2/L3 Testing in LTE 297
14.6.5 UE Test Loop Modes 297
14.7 Test Requirements in SAE 298
14.7.1 Testing at the Network Service Level 299
14.8 Throughput Testing 300
14.8.1 End-to-End Network Innovation 301
14.8.2 Base Station Scheduler as Key Controller of Radio Resources 301
14.8.3 L1 Performance vs. L3/PDCP Throughput 302
14.8.4 OTA (Over The Air) Testing 304
14.8.5 Summary 305
14.9 Self-Organizing Network Techniques for Test and Measurement 306
14.9.1 SON Definition and Basic Principles 306
14.9.2 Technical Issues and Impact on Network Planning 307
14.9.3 Effects on Network Installation, Commissioning and Optimization Strategies 308
14.9.4 Conclusion 309
14.10 Field Testing 309
14.10.1 LTE Coverage and Power Quality Measurements 311
14.10.2 Guidelines for LTE Measurements 317
References 323

15 Recommendations 325
15.1 Introduction 325
15.2 Transition to LTE—Use Cases 326
15.2.1 Total Swap 326
15.2.2 Hot Spots 326
15.3 Spectrum Aspects 327
15.3.1 General View on Spectrum Allocation 327
15.3.2 Coexistence with GSM 335
15.4 Effect of the Advanced GSM Features on the Fluent LTE Deployment 343
15.4.1 Common BCCH 344
15.4.2 AMR Full and Half Rate 347
15.4.3 Single Antenna Interference Cancellation 349
15.4.4 Orthogonal Subchannel 350
15.4.5 Antenna Hopping 354
15.4.6 EGPRS2 and Downlink Dual Carrier 357
15.4.7 Dynamic Frequency and Channel Allocation 359
15.4.8 Signaling Improvements 364
15.5 Alternative Network Migration Path (Multi-Operator Case) 367
15.5.1 Introduction to Network Sharing Variants 368
15.5.2 MORAN and MOBSS 369
15.5.3 MOCN 371
15.5.4 National Roaming, Geographical Roaming and IMSI Based Handover 374
15.6 Hardware Migration Path 376
15.6.1 Colocated Antenna Systems 377
15.6.2 Colocation with Shared Multi-Radio Base Station 380
15.7 Mobile Backhaul—Towards “All-IP” Transport 381
   15.7.1 Motivation to IP Evolution in Mobile Backhaul 381
   15.7.2 Transport Aspects in Packet Backhaul 383
15.8 LTE Interworking with Legacy Networks for the Optimal Voice and Data Services 384
   15.8.1 Intersystem Mobility Management for Data Services 385
   15.8.2 CS Fallback 394
   15.8.3 Idle Mode Signaling Reduction 404

References 405

Index 407