

NETWORKS AND TELECOMMUNICATIONS SERIES



LTE and LTE Advanced

4G Network Radio Interface

André Perez

ISTE

WILEY

LTE and LTE Advanced

4G Network Radio Interface

André Perez

ISTE

WILEY

First published 2015 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc.

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the Copyright, Designs and Patents Act 1988, this publication may only be reproduced, stored or transmitted, in any form or by any means, with the prior permission in writing of the publishers, or in the case of reprographic reproduction in accordance with the terms and licenses issued by the CLA. Enquiries concerning reproduction outside these terms should be sent to the publishers at the undermentioned address:

ISTE Ltd
27-37 St George's Road
London SW19 4EU
UK

www.iste.co.uk

John Wiley & Sons, Inc.
111 River Street
Hoboken, NJ 07030
USA

www.wiley.com

© ISTE Ltd 2015

The rights of André Perez to be identified as the author of this work have been asserted by him in accordance with the Copyright, Designs and Patents Act 1988.

Library of Congress Control Number: 2015951441

British Library Cataloguing-in-Publication Data
A CIP record for this book is available from the British Library
ISBN 978-1-84821-844-4

Preface

The aim of this book is to give an integrated presentation of the specifications for Long Term Evolution (LTE) and LTE Advanced radio interfaces, so that the reader can gain an overview of their main characteristics.

The LTE radio interface is the interface between the User Equipment (UE) and the Evolved Packet System (EPS) 4G mobile network.

The LTE radio interface was introduced in Release 8 of the specifications of the 3rd Generation Partnership Project (3GPP).

The EPS mobile network has the following features:

- it provides a data transmission service in Packet-Switched (PS) mode. The data carried by the EPS network are unicast Internet Protocol (IP) packets;
- Release 9 introduced the Multimedia Broadcast Multicast Service (MBMS) using unicast or multicast IP packets;
- Release 9 also introduced the mobile Location Services (LCS).

The LTE radio interface has the following characteristics achieving bitrates of 300 Mbps for the downlink direction and 75 Mbps for the uplink direction:

- 20-MHz radio channel bandwidth;
- 64-Quadrature Amplitude Modulation (64-QAM);

– 4×4 Multiple Input Multiple Output (MIMO) transmission mode for the downlink direction.

The LTE Advanced radio interface was introduced in Release 10.

The LTE Advanced radio interface has the following characteristics achieving bitrates of 3 Gbps for the downlink direction and 1.5 Gbps for the uplink direction:

- 100-MHz radio channel bandwidth, obtained by Carrier Aggregation (CA) of five 20-MHz radio channels;
- 8×8 MIMO transmission mode for the downlink direction;
- 4×4 MIMO transmission mode for the uplink direction.

This book is divided into 10 chapters, summarized in the following table.

Chapters	Title	Contents
1	General characteristics	EPS, MBMS, LCS networks Bearer types Radio interface Network procedures
2	NAS protocol	Attachment Session establishment
3	RRC protocol	System information Connection control Measurements Broadcast control
4	Data link layer	PDPC, RLC and MAC protocols
5	Physical layer	Frequency plan Multiplexing structure Transmission chain
6	Downlink physical signals	PSS, SSS, Cell-Specific RS, MBSFN RS, UE-Specific RS, PRS, CSI RS
7	Downlink physical channels	PBCH, PCFICH, PHICH, PDCCH, PDSCH, PMCH
8	Uplink physical signals	DM-RS, SRS
9	Uplink physical channels	PRACH, PUCCH, PUSCH
10	Radio interface procedures	Access control Data transfer

André PEREZ
September 2015

List of Acronyms

3GPP 3rd Generation Partnership Project

A

AAA Authenticate Authorize Answer
AAR Authenticate Authorize Request
ADM Activation/Deactivation MAC
AF Application Function
AKA Authentication and Key Agreement
AM Acknowledged Mode
AMBR Aggregate Maximum Bit Rate
AoA Angle of Arrival
AP Application Part
APN Access Point Name
ARP Allocation and Retention Priority
ARQ Automatic Repeat reQuest
AUTN Authentication Network

B

BCCH Broadcast Control Channel
BCH Broadcast Channel
BI Backoff Indicator
BM-SC Broadcast Multicast Service Center
BPSK Binary Phase Shift Keying
BSR Buffer Status Report

C

CA	Carrier Aggregation
CC	Component Carrier
CCCH	Common Control Channel
CCE	Control Channel Element
CDD	Cyclic Delay Diversity
CDMA	Code Division Multiple Access
CFI	Control Format Indicator
CGI	Cell Global Identity
CK	Cipher Key
CMAS	Commercial Mobile Alert System
CP	Cyclic Prefix
CPICH	Common Pilot Channel
CRC	Cyclic Redundancy Code
CRI	Contention Resolution Identity
C-RNTI	Cell RNTI
CS	Circuit-Switched
CSFB	Circuit-Switched Fallback
CSI RS	Channel State Information Reference Signal

D

DAC	Digital Analog Converter
DCCH	Dedicated Control Channel
DCI	Downlink Control Information
DL-SCH	Downlink Shared Channel
DM-RS	Demodulation Reference Signal
DNS	Domain Name Server
DRB	Data Radio Bearer
DRX	Discontinuous Reception
DSCP	DiffServ Code Point
DTCH	Dedicated Traffic Channel
DRX	Discontinuous Reception
DwPTS	Downlink Pilot Time Slot

E

EARFCN	E-UTRA Absolute Radio Frequency Channel Number
ECGI	E-UTRAN Cell Global Identifier
E CID	Enhanced Cell Identifier
EMM	EPS Mobility Management
eNB	evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-RAB	EPS Radio Access Bearer
ESM	EPS Session Management
E-SMLC	Evolved Serving Mobile Location Center
ETWS	Earthquake and Tsunami Warning System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network

F

FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FSTD	Frequency Shift Transmit Diversity

G

GBR	Guaranteed Bit Rate
GERAN	GSM/EDGE Radio Access Network
GMLC	Gateway Mobile Location Center
GNSS	Global Navigation Satellite System
GP	Gap Period
GPRS	General Packet Radio Service
GTPv2-C	GPRS Tunnel Protocol Control
GTP-U	GPRS Tunnel Protocol User
GUMMEI	Globally Unique MME Identity
GUTI	Globally Unique Temporary Identity

H

HARQ	Hybrid Automatic Repeat reQuest
HI	HARQ Indicator
HII	High Interference Indication
HeNB	Home evolved Node B

HRPD	High-Rate Packet Data
HSS	Home Subscriber Server
I	
ICIC	Inter-Cell Interference Coordination
IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
IK	Integrity Key
IMEI	International Mobile Equipment Identity
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IOI	Interference Overload Indication
IP	Internet Protocol
L	
LCID	Logical Channel Identifier
LCS	Location Services
LPP	LTE Positioning Protocol
LTE	Long Term Evolution
M	
MAC	Medium Access Control
MAC-I	Message Authentication Code for Integrity
MBMS	Multimedia Broadcast Multicast Service
MBMS GW	MBMS Gateway
MBR	Maximum Bit Rate
MBSFN	MBMS over Single-Frequency Network
MCC	Mobile Country Code
MCCH	Multicast Control Channel
MCE	Multi-cell/Multicast Coordination Entity
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MIB	Master Information Block
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MME	Mobility Management Entity

MNC	Mobile Network Code
MSI	MCH Scheduling Information
MTCH	Multicast Traffic Channel
N	
NAS	Non-Access Stratum
O	
OCC	Orthogonal Covering Code
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OTDOA	Observed Time Difference Of Arrival
P	
PA	Power Amplifier
PBCH	Physical Broadcast Channel
PCCH	Paging Control Channel
PCEF	Policy and Charging Enforcement Function
PCell	Primary Cell
PCFICH	Physical Control Format Indicator Channel
PCH	Paging Channel
PCI	Physical-layer Cell Identity
PCRF	Policy Charging and Rules Function
PDCCH	Physical Downlink Control Channel
PDCCC	Parallel Concatenated Convolutional Code
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PGW	PDN Gateway
PHICH	Physical HARQ Indicator Channel
PHR	Power Head Room
PMCH	Physical Multicast Channel
PMI	Precoding Matrix Indicator
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
P-RNTI	Paging RNTI
PRS	Positioning Reference Signal

PS	Packet-Switched
PSS	Primary Synchronization Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
Q	
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoS	Quality of Service
QPP	Quadratic Permutation Polynomial
QPSK	Quadrature Phase-Shift Keying
R	
RAA	Re-Auth Answer
RACH	Random Access Channel
RAPID	Random Access Preamble Identifier
RAR	Random Access Response
RAR	Re-Auth Request
RA-RNTI	Random Access RNTI
RAT	Radio Access Technology
RB	Resource Block
RBG	Resource Block Group
RE	Resource Element
REG	Resource Element Group
RFC	Request For Comments
RLC	Radio Link Control
RNTI	Radio Network Temporary Identifier
RNTP	Relative Narrowband Tx Power
ROHC	Robust Header Compression
RRC	Radio Resource Control
RS	Reference Signal
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indication

RTT	Round Trip Time
RV	Redundancy Version
S	
SCell	Secondary Cell
SC-FDMA	Single-Carrier Frequency Division Multiple Access
SDF	Service Data Flow
SFBC	Space-Frequency Block Code
SFN	System Frame Number
SGW	Serving Gateway
SIB	System Information Block
SIMO	Single Input Multiple Output
SI-RNTI	System Information RNTI
SISO	Single Input Single Output
SPR	Subscription Profile Repository
SPS	Semi-Persistent Scheduling
SRB	Signaling Radio Bearer
SRS	Sound Reference Signal
SSS	Secondary Synchronization Signal
S-TMSI	Shortened Temporary Mobile Subscriber Identity
T	
TA	Timing Advance
TA	Tracking Area
TAC	Tracking Area Code
TAI	Tracking Area Identity
TC-RNTI	Temporary Cell RNTI
TDD	Time Division Duplex
TEID	Tunnel Endpoint Identifier
TM	Transparent Mode
TMGI	Temporary Mobile Group Identity
TPC	Transmit Power Control
TPMI	Transmitted Precoding Matrix Indicator
TTI	Transmission Time Interval

U

UCI	Uplink Control Information
UE	User Equipment
UICC	Universal Integrated Circuit Card
UL-SCH	Uplink Shared Channel
UM	Unacknowledged Mode
UpPTS	Uplink Pilot Time Slot
USIM	Universal Services Identity Module
UTRAN	Universal Terrestrial Radio Access Network

V

VRB	Virtual Resource Block
-----	------------------------

Contents

Preface	xiii
List of Acronyms	xv
Chapter 1. General Characteristics	1
1.1. Network architecture	1
1.1.1. EPS network	1
1.1.2. MBMS network	8
1.1.3. LCS network	11
1.2. Bearer types	14
1.2.1. Bearer structure	14
1.2.2. Quality of Service	15
1.3. Radio interface	17
1.3.1. Structure of the radio interface	18
1.3.2. NAS protocol	19
1.3.3. RRC protocol	20
1.3.4. Data link layer	21
1.3.5. Logical channels	22
1.3.6. Transport channels	23
1.3.7. Physical layer	24
1.3.8. Physical signals	26
1.3.9. Physical channels	27
1.3.10. Mobile categories	29
1.4. Network procedures	30
1.4.1. Connection procedure	30
1.4.2. Attachment procedure	30
1.4.3. Restoration procedure of the default bearer	36

1.4.4. Establishment procedure of a dedicated bearer.	39
1.4.5. Location update procedure.	41
1.4.6. Handover procedure	43
1.4.7. Multicast bearer establishment procedure	45
Chapter 2. NAS Protocol	49
2.1. Attachment.	49
2.1.1. Procedure	49
2.1.2. Message structure.	51
2.2. Session establishment	55
2.2.1. Procedure	55
2.2.2. Message structure.	57
Chapter 3. RRC Protocol	63
3.1. System information	63
3.1.1. MIB message	64
3.1.2. SIB1 message	64
3.1.3. SIB2 message	66
3.1.4. SIB3 message	67
3.1.5. SIB4 message	68
3.1.6. SIB5 message	68
3.1.7. SIB6 message	68
3.1.8. SIB7 message	69
3.1.9. SIB8 message	69
3.1.10. SIB9 message	70
3.1.11. SIB10 message	70
3.1.12. SIB11 message	71
3.1.13. SIB12 message	71
3.1.14. SIB13 message	72
3.2. Connection control	72
3.2.1. Paging	72
3.2.2. Connection establishment	73
3.2.3. Security activation	75
3.2.4. Connection reconfiguration	76
3.2.5. Connection re-establishment.	78
3.2.6. Connection release	79
3.3. Measurements	80
3.3.1. Introduction	80
3.3.2. Objects.	80
3.3.3. Events	81
3.3.4. Measurement filtering	85

3.3.5. Measurement report	85
3.4. Broadcast control	85
3.4.1. Configuration of frames and subframes	85
3.4.2. MCCH logical channel scheduling	86
3.4.3. MTCH logical channel scheduling	87
3.4.4. Counting	89
Chapter 4. Data Link Layer	91
4.1. PDCP protocol	91
4.1.1. Procedures	92
4.1.2. Operations	94
4.1.3. Protocol structure	97
4.2. RLC protocol	99
4.2.1. Operations	100
4.2.2. Protocol structure	102
4.3. MAC protocol	107
4.3.1. Operations	107
4.3.2. Protocol structure	111
4.3.3. Control elements	114
Chapter 5. Physical Layer	117
5.1. Frequency plan	117
5.1.1. Frequency bands	117
5.1.2. Radio channel	119
5.1.3. Aggregation of the radio channels	121
5.1.4. Numbering of radio channels	122
5.2. Multiplexing structure	125
5.2.1. Time-division multiplexing	125
5.2.2. Resource block	130
5.2.3. Resource element group	132
5.3. Transmission chain	133
5.3.1. Error detection codes	135
5.3.2. Error correction codes	136
5.3.3. Modulation	137
5.3.4. Antenna ports	138
5.3.5. Transmission modes	140
5.3.6. Inverse Fast Fourier Transform	143
5.3.7. Configuration of the transmission	144
5.3.8. Antenna configurations	145

Chapter 6. Downlink Physical Signals	149
6.1. PSS physical signal	149
6.1.1. Sequence generation	150
6.1.2. Mapping on the resource elements	150
6.2. SSS physical signal	152
6.2.1. Sequence generation	152
6.2.2. Mapping on the resource elements	153
6.3. Cell-Specific RS physical signal	155
6.3.1. Sequence generation	155
6.3.2. Mapping on the resource elements	156
6.4. MBSFN RS physical signal	159
6.4.1. Sequence generation	159
6.4.2. Mapping on the resource elements	160
6.5. UE-Specific RS physical signal	162
6.5.1. Sequence generation	162
6.5.2. Mapping on the resource elements	164
6.6. PRS physical signal	168
6.6.1. Sequence generation	169
6.6.2. Mapping on the resource elements	169
6.6.3. Configuration of the subframes	170
6.7. CSI RS physical signal	171
6.7.1. Sequence generation	172
6.7.2. Mapping on the resource elements	173
6.7.3. Configuration of the subframes	174
 Chapter 7. Downlink Physical Channels	 177
7.1. PBCH physical channel	177
7.1.1. Error detection code	178
7.1.2. Error correction code	178
7.1.3. Rate matching	178
7.1.4. Scrambling	179
7.1.5. Modulation	179
7.1.6. Mapping on the spatial layers	179
7.1.7. Precoding	180
7.1.8. Mapping on the resource elements	181
7.2. PCFICH physical channel	182
7.2.1. CFI information	183
7.2.2. Error correction code	183
7.2.3. Scrambling	184
7.2.4. Modulation	184
7.2.5. Mapping on the spatial layers	184