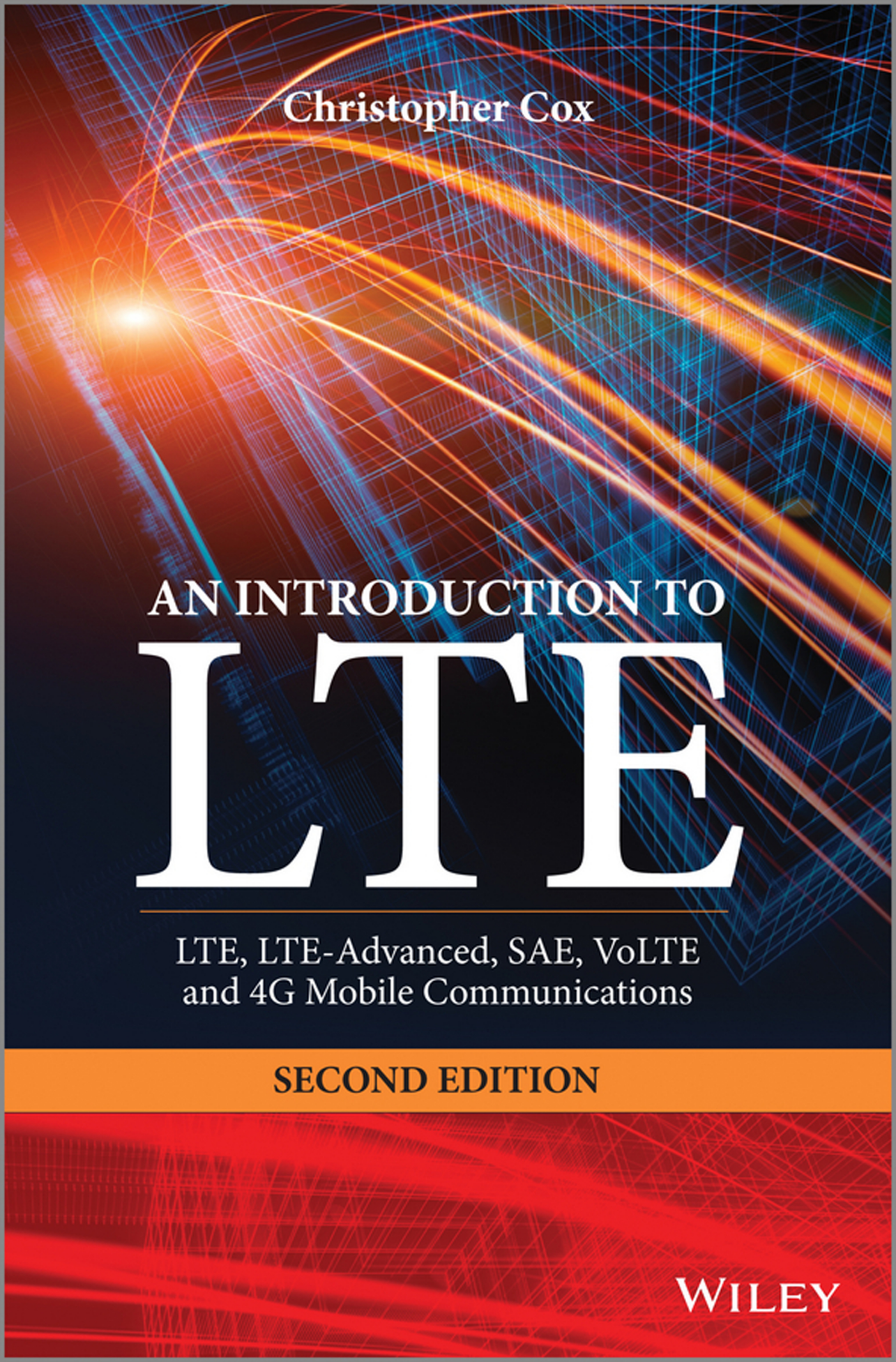
Christopher Cox
AN INTRODUCTION TO
LTE
LTE, LTE-Advanced, SAE, VoLTE
and 4G Mobile Communications
SECOND EDITION
WILEY

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LTE, LTE-ADVANCED, SAE, VoLTE AND 4G MOBILE COMMUNICATIONS

Second Edition

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WILEY

This edition first published 2014
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Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

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Library of Congress Cataloging-in-Publication Data

Cox, Christopher (Christopher Ian), 1965-
An introduction to LTE LTE, LTE-advanced, SAE, VoLTE and 4G mobile communications / Christopher Cox.
pages cm
Includes index.
ISBN 978-1-118-81803-9 (cloth)
1. Long-Term Evolution (Telecommunications) 2. Mobile communication systems – Standards. I. Title.
TK5103.48325.C693 2014
621.3845′6 – dc23

2014007432

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

ISBN:9781118818039

Set in 10/12 Times by Laserwords Private Limited, Chennai, India

To my nieces, Louise and Zoe

Contents

Preface

This book is about the world's dominant 4G mobile telecommunication system, LTE.

In writing the book, my aim has been to give the reader a concise, system level introduction to the technology that LTE uses. The book covers the whole of the system, both the techniques used for radio communication between the base station and the mobile phone, and the techniques used to transfer data and signalling messages across the network. I have avoided going into excessive detail, which is more appropriate for specialized treatments of individual topics and for the LTE specifications themselves. Instead, I hope that the reader will come away from this book with a sound understanding of the system and of the way in which its different components interact. The reader will then be able to tackle the more advanced books and the specifications with confidence.

The target audience is twofold. Firstly, I hope that the book will be valuable for engineers who are working on LTE, notably those who are transferring from other technologies such as GSM, UMTS and cdma2000, those who are experts in one part of LTE but who want to understand the system as a whole and those who are new to mobile telecommunications altogether. Secondly, the book should give a valuable overview to those who are working in non technical roles, such as project managers, marketing executives and intellectual property consultants.

Structurally, the book has four parts. The first part lays out the foundations that the reader will need in the remainder of the book. Chapter 1 is an introduction, which relates LTE to earlier mobile telecommunication systems and lays out its requirements and key technical features. Chapter 2 covers the architecture of the system, notably the hardware components and communication protocols that it contains and its use of radio spectrum. Chapter 3 reviews the radio transmission techniques that LTE has inherited from earlier mobile telecommunication systems, while Chapters 4 and 5 describe the more recent techniques of orthogonal frequency division multiple access and multiple input multiple output antennas.

The second part of the book covers the air interface of LTE. Chapter 6 is a high level description of the air interface, while Chapter 7 relates the low level procedures that a mobile phone uses when it switches on, to discover the LTE base stations that are nearby. Chapter 8 covers the low level procedures that the base station and mobile phone use to transmit and receive information, while Chapter 9 covers a specific procedure, random access, by which the mobile phone can contact a base station without prior scheduling. Chapter 10 covers the higher level parts of the air interface, namely the medium access control, radio link control and packet data convergence protocols.

The third part covers the signalling procedures that govern how a mobile phone behaves. In Chapter 11, we describe the high level procedures that a mobile phone uses when it switches on, to register itself with the network and establish communications with the outside

world. Chapter 12 covers the security procedures used by LTE, while Chapter 13 covers the procedures that manage the quality of service and charging characteristics of a data stream. Chapter 14 describes the mobility management procedures that the network uses to keep track of the mobile's location. Chapter 15 describes how LTE inter-operates with the earlier technologies of GSM and UMTS, while Chapter 16 discusses inter-operation with other technologies such as wireless local area networks and cdma2000. Chapter 17 covers the self-configuration and self-optimization capabilities of LTE.

The final part covers more specialized topics. Chapters 18, 19 and 20 describe the enhancements that have been made to LTE in later releases of the specifications, notably an enhanced version of the technology that is known as LTE-Advanced. Chapters 21 and 22 cover the two most important solutions for the delivery of voice calls to LTE devices, namely circuit switched fallback and the IP multimedia subsystem. Finally, Chapter 23 reviews the performance of LTE and discusses the techniques that are used to estimate the coverage and capacity of an LTE network.

LTE has a large number of acronyms, and it is hard to talk about the subject without using them. However, they can make the material appear unnecessarily impenetrable to a newcomer, so I have aimed to keep the use of acronyms to a reasonable minimum, often preferring the full name or a colloquial one. There is a full list of abbreviations in the introductory material and new terms are highlighted using italics throughout the text.

I have also endeavoured to keep the book's mathematical content to the minimum needed to understand the system. The LTE air interface makes extensive use of complex numbers, Fourier transforms and matrix algebra, but the reader will not require any prior knowledge of these in order to understand the book. We do make limited use of complex numbers in Chapters 3 and 4 to illustrate our discussion of modulation, and introduce Fourier transforms and matrices in subsections of Chapters 4 and 5 to cover the more advanced aspects of orthogonal frequency division multiple access and multiple antennas. Readers can, however, skip this material without detracting from their overall appreciation of the subject.

Acknowledgements

Many people have given me assistance, support and advice during the creation of this book. I am especially grateful to Liz Wingett, Susan Barclay, Sophia Travis, Sandra Grayson, Mark Hammond and the rest of the publishing team at John Wiley & Sons, Ltd for the expert knowledge and gentle encouragement that they have supplied throughout the production process.

I am indebted to Michael Salmon and Geoff Varrall for encouraging me to write the first edition of this book and to the publishing team at Wiley for requesting a second. The advice and feedback I have received while preparing the manuscript have been invaluable and have given me many opportunities to correct errors and improve the material. In this respect, I would particularly like to thank Jeff Cartwright, Joseph Hoy, Julian Nolan, Michael Salmon, Mohammad Anas, Obi Chiemeka, Pete Doherty, Les Granfield, Karl van Heeswijk, Kit Kilgour and Paul Mason. I am especially indebted to Nicola Rivers, for her support and encouragement throughout the preparation of the second edition. Naturally, the responsibility for any remaining errors or omissions in the text, and for any lack of clarity in the explanations, is entirely my own.

Much of my knowledge of the more detailed aspects of LTE, notably of circuit switched fallback and the IP multimedia subsystem, has been gathered while delivering courses on behalf of various training providers. I am indebted to the directors and staff of Imagicom, Informa Telecoms Academy, Wray Castle and Mpirical, for the support and learning opportunities that they have provided to me. I would also like to extend my thanks to the delegates who have attended my training courses on LTE. Their questions and corrections have extended my knowledge of the subject, while their feedback has regularly suggested ways to explain topics more effectively.

Several diagrams in this book have been reproduced from the technical specifications for LTE, with permission from the European Telecommunications Standards Institute (ETSI), © 2013, 2012, 2011, 2010, 2006. 3GPP™ TSs and TRs are the property of ARIB, ATIS, CCSA, ETSI, TTA and TTC who jointly own the copyright for them. They are subject to further modifications and are therefore provided to you ‘as is’ for information purposes only. Further use is strictly prohibited.

Analysys Mason Limited kindly supplied the market research data underlying the illustrations of network traffic and operator revenue in Figures 1.6 and 21.1. I would like to extend my appreciation to Hilary Bailey, Morgan Mullooly, Terry Norman and James Allen for providing this information. The measurements of network traffic in Figure 1.5 and the subscription data underlying Figures 1.9 and 1.10 are by Ericsson, and I am grateful to Elin Pettersson and Svante Bergqvist for making these available.

List of Abbreviations

16-QAM	16 quadrature amplitude modulation
1G	First generation
1xRTT	1x radio transmission technology
2G	Second generation
3G	Third generation
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
4G	Fourth generation
64-QAM	64 quadrature amplitude modulation
AAA	Authentication, authorization and accounting
ABMF	Account balance management function
ABS	Almost blank subframe
ACK	Positive acknowledgement
ACM	Address complete message
ADC	Analogue to digital converter
AES	Advanced Encryption Standard
AF	Application function/Assured forwarding
AKA	Authentication and key agreement
AM	Acknowledged mode
AMBR	Aggregate maximum bit rate
AMR	Adaptive multi rate
AMR-WB	Wideband adaptive multi rate
ANDSF	Access network discovery and selection function
ANM	Answer message
API	Application programming interface
APN	Access point name
APN-AMBR	Per APN aggregate maximum bit rate
ARIB	Association of Radio Industries and Businesses
ARP	Allocation and retention priority
ARQ	Automatic repeat request
AS	Access stratum/Application server
ASME	Access security management entity
ATCF	Access transfer control function
ATGW	Access transfer gateway
ATIS	Alliance for Telecommunications Industry Solutions

AuC	Authentication centre
AVP	Attribute value pair/Audio visual profile
AWS	Advanced Wireless Services
B2BUA	Back to back user agent
BBERF	Bearer binding and event reporting function
BBF	Bearer binding function
BCCH	Broadcast control channel
BCH	Broadcast channel
BD	Billing domain
BE	Best effort
BGCF	Breakout gateway control function
BICC	Bearer independent call control
BM-SC	Broadcast/multicast service centre
BPSK	Binary phase shift keying
BSC	Base station controller
BSR	Buffer status report
BSSAP+	Base station subsystem application part plus
BSSGP	Base station system GPRS protocol
BTS	Base transceiver station
CA	Carrier aggregation
CAMEL	Customized applications for mobile network enhanced logic
CBC	Cell broadcast centre
CBS	Cell broadcast service
CC	Call control/Component carrier
CCCH	Common control channel
CCE	Control channel element
CCO	Cell change order
CCSA	China Communications Standards Association
CDF	Charging data function
CDMA	Code division multiple access
CDR	Charging data record
CFI	Control format indicator
CGF	Charging gateway function
CIF	Carrier indicator field
CLI	Calling line identification
CM	Connection management
CMAS	Commercial mobile alert system
C-MSISDN	Correlation mobile subscriber ISDN number
CoMP	Coordinated multi-point transmission and reception
COST	European Cooperation in Science and Technology
CP	Cyclic prefix
CQI	Channel quality indicator
CRC	Cyclic redundancy check
C-RNTI	Cell radio network temporary identifier
CS	Circuit switched

CS/CB	Coordinated scheduling and beamforming
CSCF	Call session control function
CSFB	Circuit switched fallback
CSG	Closed subscriber group
CSI	Channel state information
CS-MGW	Circuit switched media gateway
CTF	Charging trigger function
D2D	Device to device
DAC	Digital-to-analogue converter
dB	Decibel
dBi	Decibels relative to an isotropic antenna
dBm	Decibels relative to one milliwatt
DCCH	Dedicated control channel
DCI	Downlink control information
DeNB	Donor evolved Node B
DFT	Discrete Fourier transform
DFT-S-OFDMA	Discrete Fourier transform spread OFDMA
DHCP	Dynamic host configuration protocol
DiffServ	Differentiated services
DL	Downlink
DL-SCH	Downlink shared channel
DNS	Domain name server
DPS	Dynamic point selection
DRS	Demodulation reference signal
DRVCC	Dual radio voice call continuity
DRX	Discontinuous reception
DSCP	Differentiated services code point
DSL	Digital subscriber line
DSMIP	Dual-stack mobile IP
DTCH	Dedicated traffic channel
DTM	Dual transfer mode
DTMF	Dual tone multi-frequency
EAG	Explicit array gain
eAN	Evolved access network
EAP	Extensible authentication protocol
EATF	Emergency access transfer function
ECGI	E-UTRAN cell global identifier
ECI	E-UTRAN cell identity
ECM	EPS connection management
ECN	Explicit congestion notification
E-CSCF	Emergency call session control function
EDGE	Enhanced Data Rates for GSM Evolution
EEA	EPS encryption algorithm
EF	Expedited forwarding
eHRPD	Evolved high rate packet data

EIA	EPS integrity algorithm
EICIC	Enhanced inter cell interference coordination
EIR	Equipment identity register
EIRP	Equivalent isotropic radiated power
eMBMS	Evolved MBMS
EMM	EPS mobility management
eNB	Evolved Node B
EPC	Evolved packet core
ePCF	Evolved packet control function
EPDCCH	Enhanced physical downlink control channel
ePDG	Evolved packet data gateway
EPRE	Energy per resource element
EPS	Evolved packet system
E-RAB	Evolved radio access bearer
ERF	Event reporting function
ESM	EPS session management
E-SMLC	Evolved serving mobile location centre
ESP	Encapsulating security payload
ETSI	European Telecommunications Standards Institute
ETWS	Earthquake and tsunami warning system
E-UTRAN	Evolved UMTS terrestrial radio access network
EV-DO	Evolution data optimized
FCC	Federal Communications Commission
FDD	Frequency division duplex
FDMA	Frequency division multiple access
FD-MIMO	Full-dimension MIMO
FFT	Fast Fourier transform
FTP	File transfer protocol
GBR	Guaranteed bit rate
GCP	Gateway control protocol
GERAN	GSM EDGE radio access network
GGSN	Gateway GPRS support node
GMLC	Gateway mobile location centre
GMM	GPRS mobility management
GNSS	Global navigation satellite system
GP	Guard period
GPRS	General Packet Radio Service
GPS	Global Positioning System
GRE	Generic routing encapsulation
GRX	GPRS roaming exchange
GSM	Global System for Mobile Communications
GSMA	GSM Association
GTP	GPRS tunnelling protocol
GTP-C	GPRS tunnelling protocol control part
GTP-U	GPRS tunnelling protocol user part