Third Edition

4G

LTE-Advanced Pro and The Road to 5G

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Preface

LTE has become the most successful mobile wireless broadband technology, serving over one billion users as of the beginning of 2016 and handling a wide range of applications. Compared to the analog voice-only systems 25 years ago, the difference is dramatic. Although LTE is still at a relatively early stage of deployment, the industry is already well on the road toward the next generation of mobile communication, commonly referred to as the fifth generation or 5G. Mobile broadband is, and will continue to be, an important part of future cellular communication, but future wireless networks are to a large extent also about a significantly wider range of use cases and a correspondingly wider range of requirements.

This book describes LTE, developed in 3GPP (*Third-Generation Partnership Project*) and providing true fourth-generation (4G) broadband mobile access, as well as the new radio-access technology 3GPP is currently working on. Together, these two technologies will provide 5G wireless access.

Chapter 1 provides a brief introduction, followed by a description of the standardization process and relevant organizations such as the aforementioned 3GPP and ITU in Chapter 2. The frequency bands available for mobile communication are also be covered, together with a discussion on the process for finding new frequency bands.

An overview of LTE and its evolution is found in Chapter 3. This chapter can be read on its own to get a high-level understanding of LTE and how the LTE specifications evolved over time. To underline the significant increase in capabilities brought by the LTE evolution, 3GPP introduced the names LTE-Advanced and LTE-Advanced Pro for some of the releases.

Chapters 4−11 cover the basic LTE structure, starting with the overall protocol structure in Chapter 4 and followed by a detailed description of the physical layer in Chapters 5−7. The remaining Chapters 8−11, cover connection setup and various transmission procedures, including multi-antenna support.

Some of the major enhancements to LTE introduced over time is covered in Chapters 12−21, including carrier aggregation, unlicensed spectrum, machine-type communication, and device-to-device communication. Relaying, heterogeneous deployments, broadcast/multicast services, and dual connectivity multi-site coordination are other examples of enhancements covered in these chapters.

Radio frequency (RF) requirements, taking into account spectrum flexibility and multi-standard radio equipment, is the topic of Chapter 22.

Chapters 23 and 24 cover the new radio access about to be standardized as part of 5G. A closer look on the requirements and how they are defined is the topic of Chapter 23, while Chapter 24 digs into the technical realization.

Finally, Chapter 25 concludes the book and the discussion on 5G radio access.

Acknowledgments

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The standardization process involves people from all parts of the world, and we acknowledge the efforts of our colleagues in the wireless industry in general and in 3GPP RAN in particular. Without their work and contributions to the standardization, this book would not have been possible.

Finally, we are immensely grateful to our families for bearing with us and supporting us during the long process of writing this book.

Abbreviations and Acronyms

3GPP	Third-generation partnership project
AAS	Active antenna systems
ACIR	Adjacent channel interference ratio
ACK	Acknowledgment (in ARQ protocols)
ACLR	Adjacent channel leakage ratio
ACS	Adjacent channel selectivity
AGC	Automatic gain control
AIFS	Arbitration interframe space
AM	Acknowledged mode (RLC configuration)
A-MPR	Additional maximum power reduction
APT	Asia-Pacific telecommunity
ARI	Acknowledgment resource indicator
ARIB	Association of radio industries and businesses
ARQ	Automatic repeat-request
AS	Access stratum
ATC	Ancillary terrestrial component
ATIS	Alliance for telecommunications industry solutions
AWGN	Additive white Gaussian noise
BC	Band category
BCCH	Broadcast control channel
BCH	Broadcast channel
BL	Bandwidth-reduced low complexity
BM-SC	Broadcast multicast service center
BPSK	Binary phase-shift keying
BS	Base station
BW	Bandwidth
CA	Carrier aggregation
CACLR	Cumulative adjacent channel leakage ratio
CC	Component carrier
CCA	Clear channel assessment
CCCH	Common control channel
CCE	Control channel element
CCSA	China Communications Standards Association
CDMA	Code-division multiple access
CE	Coverage enhancement
CEPT	European Conference of Postal and Telecommunications Administrations
CGC	Complementary ground component
CITEL	Inter-American Telecommunication Commission
C-MTC	Critical MTC
CN	Core network
CoMP	Coordinated multi-point transmission/reception
CP	Cyclic prefix
CQI	Channel-quality indicator

CRC	Cyclic redundancy check
C-RNTI	Cell radio-network temporary identifier
CRS	Cell-specific reference signal
CS	Capability set (for MSR base stations)
CSA	Common subframe allocation
CSG	Closed Subscriber Group
CSI	Channel-state information
CSI-IM	CSI interference measurement
CSI-RS	CSI reference signals
CW	Continuous wave
D2D	Device-to-device
DAI	Downlink assignment index
DCCH	Dedicated control channel
DCH	Dedicated channel
DCI	Downlink control information
DCF	Distributed coordination function
DFS	Dynamic frequency selection
DFT	Discrete Fourier transform
DFTS-OFDM	DFT-spread OFDM (DFT-precoded OFDM)
DIFS	Distributed interframe space
DL	Downlink
DL-SCH	Downlink shared channel
DM-RS	Demodulation reference signal
DMTC	DRS measurements timing configuration
DRS	Discovery reference signal
DRX	Discontinuous reception
DTCH	Dedicated traffic channel
DTX	Discontinuous transmission
DwPTS	Downlink part of the special subframe (for TDD operation)
ECCE	Enhanced control channel element
EDCA	Enhanced distributed channel access
EDGE	Enhanced data rates for GSM evolution; enhanced data rates for global evolution
eIMTA	Enhanced Interference mitigation and traffic adaptation
EIRP	Effective isotropic radiated power
EIS	Equivalent isotropic sensitivity
EMBB	Enhanced MBB
eMTC	Enhanced machine-type communication
eNB	eNodeB
eNodeB	E-UTRAN NodeB
EPC	Evolved packet core
EPDCCH	Enhanced physical downlink control channel
EPS	Evolved packet system
EREG	Enhanced resource-element group
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved UTRA

E-UTRAN	Evolved UTRAN
EVM	Error vector magnitude
FCC	Federal Communications Commission
FDD	Frequency division duplex
FD-MIMO	Full-dimension multiple input—multiple output
FDMA	Frequency-division multiple access
FEC	Forward error correction
FeICIC	Further enhanced intercell interference coordination
FFT	Fast Fourier transform
FPLMTS	Future public land mobile telecommunications systems
FSTD	Frequency-switched transmit diversity
GB	Guard band
GERAN	GSM/EDGE radio access network
GP	Guard period (for TDD operation)
GPRS	General packet radio services
GPS	Global positioning system
GSM	Global system for mobile communications
GSMA	GSM Association
HARQ	Hybrid ARQ
HII	High-interference indicator
HSFN	Hypersystem frame number
HSPA	High-speed packet access
HSS	Home subscriber server
ICIC	Intercell interference coordination
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICS	In-channel selectivity
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse fast Fourier transform
IMT-2000	International Mobile Telecommunications 2000 (ITU's name for the family of 3G standards)
IMT-2020	International Mobile Telecommunications 2020 (ITU's name for the family of 5G standards)
IMT-Advanced	International Mobile Telecommunications Advanced (ITU's name for the family of 4G standards).
IOT	Internet of things
IP	Internet protocol
IR	Incremental redundancy
IRC	Interference rejection combining
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union—Radio communications sector
KPI	Key performance indicator
LAA	License-assisted access
LAN	Local area network
LBT	Listen before talk
LCID	Logical channel identifier
LDPC	Low-density parity check code
LTE	Long-term evolution

MAC	Medium access control
MAN	Metropolitan area network
MBB	Mobile broadband
MBMS	Multimedia broadcast—multicast service
MBMS-GW	MBMS gateway
MB-MSR	Multi-band multi-standard radio (base station)
MBSFN	Multicast—broadcast single-frequency network
MC	Multi-carrier
MCCH	MBMS control channel
MCE	MBMS coordination entity
MCG	Master cell group
MCH	Multicast channel
MCS	Modulation and coding scheme
METIS	Mobile and wireless communications Enablers for Twenty—twenty (2020) Information Society
MIB	Master information block
MIMO	Multiple input—multiple output
MLSE	Maximum-likelihood sequence estimation
MME	Mobility management entity
M-MTC	Massive MTC
MPDCCH	MTC physical downlink control channel
MPR	Maximum power reduction
MSA	MCH subframe allocation
MSI	MCH scheduling information
MSP	MCH scheduling period
MSR	Multi-standard radio
MSS	Mobile satellite service
MTC	Machine-type communication
MTCH	MBMS traffic channel
MU-MIMO	Multi-user MIMO
NAK	Negative acknowledgment (in ARQ protocols)
NAICS	Network-assisted interference cancelation and suppression
NAS	Non-access stratum (a functional layer between the core network and the terminal that supports signaling)
NB-IoT	Narrow-band internet of things
NDI	New data indicator
NGMN	Next-generation mobile networks
NMT	Nordisk MobilTelefon (Nordic Mobile Telephony)
NodeB	A logical node handling transmission/reception in multiple cells; commonly, but not necessarily, corresponding to a base station
NPDCCH	Narrowband PDCCH
NPDSCH	Narrowband PDSCH
NS	Network signaling
OCC	Orthogonal cover code
OFDM	Orthogonal frequency-division multiplexing

OI	Overload indicator
OOB	Out-of-band (emissions)
OSDD	OTA sensitivity direction declarations
OTA	Over the air
PA	Power amplifier
PAPR	Peak-to-average power ratio
PAR	Peak-to-average ratio (same as PAPR)
PBCH	Physical broadcast channel
PCCH	Paging control channel
PCFICH	Physical control format indicator channel
PCG	Project Coordination Group (in 3GPP)
PCH	Paging channel
PCID	Physical cell identity
PCRF	Policy and charging rules function
PDC	Personal digital cellular
PDCCH	Physical downlink control channel
PDCP	Packet data convergence protocol
PDSCH	Physical downlink shared channel
PDN	Packet data network
PDU	Protocol data unit
P-GW	Packet-data network gateway (also PDN-GW)
PHICH	Physical hybrid-ARQ indicator channel
PHS	Personal handy-phone system
PHY	Physical layer
PMCH	Physical multicast channel
PMI	Precoding-matrix indicator
PRACH	Physical random access channel
PRB	Physical resource block
P-RNTI	Paging RNTI
ProSe	Proximity services
PSBCH	Physical sidelink broadcast channel
PSCCH	Physical sidelink control channel
PSD	Power spectral density
PSDCH	Physical sidelink discovery channel
P-SLSS	Primary sidelink synchronization signal
PSM	Power-saving mode
PSS	Primary synchronization signal
PSSCH	Physical sidelink shared channel
PSTN	Public switched telephone networks
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QCL	Quasi-colocation
QoS	Quality-of-service
QPP	Quadrature permutation polynomial

QPSK	Quadrature phase-shift keying
RAB	Radio-access bearer
RACH	Random-access channel
RAN	Radio-access network
RA-RNTI	Random-access RNTI
RAT	Radio-access technology
RB	Resource block
RE	Resource element
REG	Resource-element group
RF	Radio frequency
RI	Rank indicator
RLAN	Radio local area networks
RLC	Radio link control
RNTI	Radio-network temporary identifier
RNTP	Relative narrowband transmit power
RoAoA	Range of angle of arrival
ROHC	Robust header compression
R-PDCCH	Relay physical downlink control channel
RRC	Radio-resource control
RRM	Radio resource management
RS	Reference symbol
RSPC	Radio interface specifications
RSRP	Reference signal received power
RSRQ	Reference signal received quality
RV	Redundancy version
RX	Receiver
S1	Interface between eNodeB and the evolved packet core
S1-c	Control-plane part of S1
S1-u	User-plane part of S1
SAE	System architecture evolution
SBCCH	Sidelink broadcast control channel
SCG	Secondary cell group
SCI	Sidelink control information
SC-PTM	Single-cell point to multipoint
SDMA	Spatial division multiple access
SDO	Standards developing organization
SDU	Service data unit
SEM	Spectrum emissions mask
SF	Subframe
SFBC	Space–frequency block coding
SFN	Single-frequency network (in general, see also MBSFN); system frame number (in 3GPP).
S-GW	Serving gateway
SI	System information message
SIB	System information block
SIB1-BR	SIB1 bandwidth reduced

SIC	Successive interference combining
SIFS	Short interframe space
SIM	Subscriber identity module
SINR	Signal-to-interference-and-noise ratio
SIR	Signal-to-interference ratio
SI-RNTI	System information RNTI
SL-BCH	Sidelink broadcast channel
SL-DCH	Sidelink discovery channel
SLI	Sidelink identity
SL-SCH	Sidelink shared channel
SLSS	Sidelink synchronization signal
SNR	Signal-to-noise ratio
SORTD	Spatial orthogonal-resource transmit diversity
SR	Scheduling request
SRS	Sounding reference signal
S-SLSS	Secondary sidelink synchronization signal
SSS	Secondary synchronization signal
STCH	Sidelink traffic channel
STBC	Space—time block coding
STC	Space—time coding
STTD	Space—time transmit diversity
SU-MIMO	Single-user MIMO
TAB	Transceiver array boundary
TCP	Transmission control protocol
TC-RNTI	Temporary C-RNTI
TDD	Time-division duplex
TDMA	Time-division multiple access
TD-SCDMA	Time-division-synchronous code-division multiple access
TF	Transport format
TPC	Transmit power control
TR	Technical report
TRP	Time repetition pattern; transmission reception point
TRPI	Time repetition pattern index
TS	Technical specification
TSDSI	Telecommunications Standards Development Society, India
TSG	Technical Specification Group
TTA	Telecommunications Technology Association
TTC	Telecommunications Technology Committee
TTI	Transmission time interval
TX	Transmitter
TXOP	Transmission opportunity
UCI	Uplink control information
UE	User equipment (the 3GPP name for the mobile terminal)
UEM	Unwanted emissions mask
UL	Uplink

UL-SCH	Uplink shared channel
UM	Unacknowledged mode (RLC configuration)
UMTS	Universal mobile telecommunications system
UpPTS	Uplink part of the special subframe, for TDD operation
URLLC	Ultra-reliable low-latency communication
UTRA	Universal terrestrial radio access
UTRAN	Universal terrestrial radio-access network
VoIP	Voice-over-IP
VRB	Virtual resource block
WARC	World Administrative Radio Congress
WAS	Wireless access systems
WCDMA	Wideband code-division multiple access
WCS	Wireless communications service
WG	Working group
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network
WMAN	Wireless metropolitan area network
WP5D	Working Party 5D
WRC	World Radio communication Conference
X2	Interface between eNodeBs.
ZC	Zadoff-Chu