Design, Deployment and Performance of 4G LTE Networks

A Practical Approach

Ayman ElNashar | Mohamed A. El-saidny | Mahmoud Sherif

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A PRACTICAL APPROACH

Ayman Elnashar
Emirates Integrated Telecomms Co., UAE

Mohamed A. El-saidny
QUALCOMM Technologies, Inc., USA

Mahmoud R. Sherif
Emirates Integrated Telecomms Co., UAE

WILEY

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To my beloved kids Noursin, Amira, and Yousef. You're the inspiration!

This book is dedicated to the memory of my father (God bless his soul) and also my mother, who's been a rock of stability throughout my life. This book is also dedicated to my beloved wife whose consistent support and patience sustain me still.

My sincerest appreciations for a lifetime career that has surpassed anything my imagination could have conceived.

Ayman Elnashar

To my Family for all their continuous support. To my elder brother for his guidance and motivation throughout the years. To my inspirational, intelligent, and beautiful daughter, Hana.

Your work is going to fill a large part of your life, and the only way to be truly satisfied is to do what you believe is great work. And the only way to do great work is to love what you do. If you haven't found it yet, keep looking. Don't settle. As with all matters of the heart, you'll know when you find it. – Steve Jobs

Mohamed A. El-saidny

This work would not have been possible without the consistent and full support of my beloved family. To my beloved wife, Meram, to my intelligent, motivating, and beautiful kids, Moustafa, Tasneem, and Omar. You are my inspiration.

To my Dad, my Mom (God bless her soul), my brother, and my entire family. Thank you for all your support and encouragement.

There is no elevator to success. You have to take the stairs. – Unknown Author

Those who think they have found this elevator will end up falling down the elevator shaft

Mahmoud R. Sherif

Contents

Authors' Biographies

Ayman Elnashar was born in Egypt in 1972. He received the B.S. degree in electrical engineering from Alexandria University, Alexandria, Egypt, in 1995 and the M.Sc. and Ph.D. degrees in electrical communications engineering from Mansoura University, Mansoura, Egypt, in 1999 and 2005, respectively. He obtained his M.Sc. and Ph.D. degrees while working fulltime. He has more than 17 years of experience in telecoms industry including GSM, GPRS/EDGE, UMTS/HSPA+/LTE, WiMax, WiFi, and transport/backhauling technologies. He was part of three major start-up telecom operators in MENA region (Mobinil/Egypt, Mobily/KSA, and du/UAE) and held key leadership positions. Currently, he is Sr. Director of Wireless Broadband, Terminals, and Performance with the Emirates Integrated Telecommunications Co. "du", UAE. He is in charge of mobile and fixed wireless broadband networks. He is responsible for strategy and innovation, design and planning, performance and optimization, and rollout/implementation of mobile and wireless broadband networks. He is the founder of the Terminals department and also the terminals lab for end-to-end testing, validation, and benchmarking of mobile terminals. He managed and directed the evolution, evaluation, and introduction of du mobile broadband HSPA+/LTE networks. Prior to this, he was with Mobily, Saudi Arabia, from June 2005 to Jan 2008 and with Mobinil (orange), Egypt, from March 2000 to June 2005. He played key role in contributing to the success of the mobile broadband network of Mobily/KSA.

He managed several large-scale networks, and mega projects with more than 1.5 billion USD budgets including start-ups (LTE 1800 MHz, UMTS, HSPA+, and WiMAX16e), networks expansions (GSM, UMTS/HSPA+, WiFi, and transport/backhauling) and swap projects (GSM, UMTS, MW, and transport network) from major infrastructure vendors. He obtained his PhD degree in multiuser interference cancellation and smart antennas for cellular systems. He published 20+ papers in wireless communications arena in highly ranked journals such as *IEEE Transactions on Antenna and Propagation, IEEE Transactions Vehicular technology, and IEEE Transactions Circuits and Systems I, IEEE Vehicular technology Magazine, IET Signal Processing*, and international conferences. His research interests include practical performance analysis of cellular systems (CDMA-based & OFDM-based), 3G/4G mobile networks planning, design, and Optimization, digital signal processing for wireless communications, multiuser detection, smart antennas, MIMO, and robust adaptive detection and beamforming. He is currently working on LTE-Advanced and beyond including eICIC, HetNet, UL/DL CoMP, 3D Beamforming, Combined LTE/HSPA+, Combined LTE/WiFi: simultaneous reception, etc …

Mohamed A. El-saidny is a technical expert with 10+ years of international technical and leadership experience in wireless communication systems for mobile phones, modem chipsets, and networks operators. He received the B.Sc. degree in Computer Engineering and the M.Sc.

degree in Electrical Engineering from the University of Alabama in Huntsville, USA in 2002 and 2004, respectively. From 2004 to 2008, he worked in Qualcomm CDMA Technology, Inc. (QCT), San Diego, California, USA. He was responsible for performance evaluation and analysis of the Qualcomm UMTS system and software solutions used in user equipment. As part of his assignments, he developed and implemented system studies to optimize the performance of various UMTS algorithms. The enhancements utilize Cell re-selection, Handover, Cell Search and Paging. He worked on several IOT and field trials to evaluate and improve the performance of 3G systems. Since 2008, he has been working in Qualcomm Corporate Engineering Services division in Dubai, UAE. He has been working on expanding the 3G/4G technologies footprints with operators, with an additional focus on user equipment and network performance as well as technical roadmaps related to the industry. Mohamed is currently supporting operators in Middle East and North Africa in addition to worldwide network operators and groups in LTE commercial efforts. His responsibilities are to ensure the device and network performance are within expectations. He led a key role in different first time features evaluations such as CSFB, C-DRX, IRAT, and load balance techniques in LTE. As part of this role, he is focused on aligning network operators to the device and chipset roadmaps and products in both 3G and 4G. Mohamed is the author of several international IEEE journal papers and contributions to 3GPP, and an inventor of numerous patents.

Mahmoud R. Sherif is a leading technical expert with more than 18 years of international experience in the design, development and implementation of fourth generation mobile broadband technologies and networks. He received his Ph.D. degree in Electrical Engineering from the City University of New York, USA in February 2000. His Ph.D. degree was preceded by the B.Sc. degree in Computer Engineering and the M.Sc. degree in Electrical Engineering from the University of Ain Shams in Cairo, Egypt in 1992, and 1996, respectively. From 1997 to 2008, he was working in the Wireless Business Unit at Lucent Technologies (which became Alcatel-Lucent in 2007), in Whippany, New Jersey, USA. He led the Voice and Data Quality and Performance Analysis team responsible for the end-to-end performance analysis of the different wireless/mobile technologies. In November 2008, he moved to Dubai in the United Arab Emirates to join the Emirates Integrated Telecommunications Co. "du" where he is now the Head of the Mobile Access Planning within du (Senior Director Mobile Access Planning) managing the Radio Planning, Site Acquisition and Capacity and Feature Management Departments. He is responsible for managing the planning of the mobile access network nationwide, Mobile Sites' Acquisition, Strategic Planning on Mobile Access Network Capacity Management, all Feature testing and rollout across 2G, 3G and LTE, defining and managing the financial resources efficiently and with alignment with company's financial targets (CAPEX & OPEX). He is also responsible for the mobile access network technology strategy in coordination with the commercial and marketing teams. He is considered a company expert resource in the various mobile broadband technologies, including HSPA+, LTE, VoLTE and LTE-A. He has published several related papers in various technical journals as well as multiple international conferences. He has multiple contributions to the 3GPP and other telecommunications standards. He also has multiple granted patents in the USA.

Preface

Cellular mobile networks have been evolving for many years. Several cellular systems and networks have been developed and deployed worldwide to provide the end user with quality and reliable communication over the air. Mobile technologies from the first to third generation have been quickly evolving to meet the need of services for voice, video, and data.

Today, the transition to smartphones has steered the user's interest toward a more mobile-based range of applications and services, increasing the demand for more network capacity and bandwidth. Meanwhile, this transition presents a significant revenue opportunity for network operators and service providers, as there is substantially higher average revenue per user (ARPU) from smartphone sales and relevant services. While the rollout of more advanced radio networks is proceeding rapidly, smartphone penetration is also increasing exponentially. Therefore, network operators need to ensure that the subscribers' experience stays the same as, or is even better than, with the older existing systems.

With the growing demand for data services, it is becoming increasingly challenging to meet the required data capacity and cell-edge spectrum efficiency. This adds more demand on the network operators, vendors and device providers to apply methods and features that stabilize the system's capacity and consequently improves the end-user experience. 4G systems and relevant advanced features have the capabilities to keep up with today's widespread use of mobile-communication devices, providing a range of mobile services and quality communications.

This book describes the long term evolution (LTE) technology for mobile systems; a transition from third to fourth generation. LTE has been developed in the 3GPP (Third Generation Partnership Project), starting from the first version in Release 8 and through to the continuing evolution to Release 10, the latest version of LTE, also known as LTE-Advanced. The analysis in this book is based on the LTE of 3GPP Release 8 together with Release 9 and Release 10 roadmaps, with a focus on the LTE-FDD (frequency division duplex) mode . Unlike other books, the authors have bridged the gap between theory and practice, thanks to hands on experience in the design, deployment, and performance of commercial 4G-LTE networks and terminals.

The book is a practical guide for 4G networks designers, planners, and optimizers, as well as other readers with different levels of expertise. The book brings extensive and broad practical hands-on experience to the readers. Practical scenarios and case studies are provided, including performance aspects, link budgets, end-to-end architecture, end-to-end QoS (quality of service) topology, dimensioning exercises, field measurement results, applicable business case studies, and roadmaps.

Chapters 1 and 2 describe the LTE system architecture, interfaces, and protocols. They also introduce the LTE air interface and layers, in addition to downlink and uplink channels and procedures.

Chapters 3 to 8 constitute the main part of the book. They provide a deeper insight into the LTE system features, performance, design aspects, deployment scenarios, planning exercises, VoLTE (voice over long term evolution) implementation, and the evolution and roadmap to LTE-Advanced. Further material supporting this book can be found in www.ltehetnet.com.

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Abbreviations and Acronyms

16-QAM	16-Quadrature amplitude modulation
64-QAM	64-Quadrature amplitude modulation
1G, 2G, 3G or 4G	1st, 2nd, 3rd, 4th generation
3GPP	Third generation partnership project
3GPP2	Third generation partnership project 2
AAA	Authentication, authorization and accounting
ACK	Acknowledgment
AES	Advanced encryption standard
AF	Application Function
AIPN	All-IP network
AMBR	Aggregate maximum bit rate
AMC	Adaptive modulation and coding
AMD	Acknowledged mode data
AN	Access network
APN	Access point name
ARP	Allocation and retention priority
ARQ	Automatic repeat request
AS	Access stratum
BC	Business Case
BCCH	Broadcast control channel
BCH	Broadcast channel
BI	Backoff indicator
BLER	Block error rate
BP	Bandwidth part
BSR	Buffer status report
BW	Bandwidth
CAPEX	Capital Expenditure
CCCH	Common control channel
CCE	Control channel elements
CDD	Cyclic delay diversity
CDM	Code Division Multiplexed
CDMA	Code division multiple access

CDS	Channel dependent scheduling
CFI	Control format indicator
CN	Core network
COGS	Cost of Goods Sold
CP	Control plane
	Cyclic prefix
CQI	Channel quality indicator
CRC	Cyclic redundancy check
CRF	Charging Rules Function
C-RNTI	Cell radio network temporary identifier
CS	Circuit switched
CSG	Closed subscriber group
CSI	Channel signal information
CW	Code word
DAS	Distributed Antenna System
DCCH	Dedicated control channel
DCI	Downlink control information
DFT	Discrete Fourier transform
DFTS-OFDM	Discrete Fourier transform spread orthogonal frequency division multiplexing
DL	Downlink
DL-SCH	Downlink shared channel
DM	Demodulation
DM-RS	Demodulation reference signal
DNS	Domain Name System
DRX	Discontinuous transmission
DS	Data services
DTCH	Dedicated traffic channel
E-AGCH	Enhanced absolute granting channel
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
E-DCH	Enhanced dedicated channel
E-DPCCH	Enhanced dedicated physical control channel
E-DPDCH	Enhanced dedicated physical data channel
E-HICH	Enhanced hybrid indicator channel
EEA	EPS encryption algorithm
EIA	EPS integrity algorithm
EIR	Equipment Identity register
EMM	EPS mobility management
eNB	Evolved node B
EPC	Evolved packet core
EPLMN	Equivalent PLMN
EPRE	Energy per resource element
EPS	Evolved packet system
E-RGCH	Enhanced relative granting channel
ESM	EPS session management
ESP	Encapsulated security protocol

ETWS	Earthquake and tsunami warning system
E-UTRA	Evolved UMTS terrestrial radio access; PHY aspects
E-UTRAN	Evolved UMTS terrestrial radio access network; MAC/L2/L3 aspects
FD	Full-duplex
FDD	Frequency division duplex
FDM	Frequency division multiplexing
FDMA	Frequency division multiple access
FFT	Fast Fourier transform
FH	Frequency hopping
FI	Framing information
FL	Forward link
FMS	First missing sequence
FS	Frame structure
FSTD	Frequency shift time diversity
GBR	Guaranteed bit rate
GERAN	GSM/EDGE radio access network
GGSN	GPRS gateway support node
GPRS	General packet radio service
GSM	Global system for mobiles (European standard)
GTP-U	GPRS tunneling protocol – user
GUMMEI	Globally unique MME identity
GUTI	Globally unique temporary identifier
GW	Gateway
HA	Home agent
HAP ID	HARQ process ID
HARQ	Hybrid ARQ
HD	Half-duplex
HFN	Hyper frame number
HI	Hybrid ARQ indicator
HLD	High Level Design
HLR	Home location register
HNBID	Home evolved node B identifier
HO	Handover
HPLMN	Home public land mobile network
HRPD	High rate packet data
HS	High speed
HSDPA	High speed downlink packet access
HS-DPCCH	High speed dedicated control channel
HSPA	High speed packet access
HSPA+	High speed packet access evolved or enhanced
HSS	Home subscriber service
HSUPA	High speed uplink packet access
IDFT	Inverse discrete Fourier transform
IETF	Internet Engineering Task Force
IFFT	Inverse fast Fourier transform
IMS	IP Multimedia subsystem

IMSI	International Mobile Subscriber Identity
IP	Internet protocol
IP-CAN	IP connectivity access network
ISI	Inter-symbol interference
ISR	Idle signaling load reduction
IRR	Internal Rate of Return
L1, L2, L3	Layer 1, 2, 3
LA	Location area
LAC	Location area code
LAI	Location area identifier
LAU	Location area updating
LCG	Logical channel group
LDAP	Lightweight Directory Access
LFDM	Localized frequency division multiplexing
LI	Lawful Interception
LI	Length indicators
LTE	Long term evolution
LTI	Linear time invariant
MAC	Medium access control
MAC-I	Message authentication code for integrity
MBMS	Multimedia broadcast multicast service
MBR	Maximum bit rate
MBSFN	Multimedia broadcast over a single frequency network
MCCH	Multicast control channel
MCH	Multicast channel
MCS	Modulation and coding schemes
MCW	Multiple code word
ME	Mobile equipment
MIB	Master information block
MIMO	Multiple-input–multiple-output
MME	Mobility management entity
MMEC	MME code
MMEGI	MME group ID
MSISDN	Mobile Subscriber Integrated Services Digital Network-Number
MOS	Mean Opinion Score
MTCH	Multicast traffic channel
MU-MIMO	Multi-user multiple-input–multiple-output
NAK	Negative acknowledgment
NAS	Non-access stratum
NDI	New data indicator
NID	Network ID
NPV	Net Present Value
OCS	Online Charging System
OFCS	Offline Charging System
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access

OS	Operating system
PAPR	Peak-to-average power ratio
PAR	Peak to average ratio
PBCH	Physical broadcast channel
PCC	Policy charging and control
PCCH	Paging control channel
PCFICH	Physical control format indicator channel
PCH	Paging channel
PCRF	Policy and charging rules function
PDCCH	Physical downlink control channel
PDCP	Packet data convergence protocol
PDG	Packet data gateway
PDN	Packet data network
PDSCH	Physical downlink shared channel
PDSN	Packet data serving node
PDU	Protocol data unit
PELR	Packet error loss rate
P-GW	Packet data network gateway
PHICH	Physical hybrid automatic repeat request indicator channel
PHR	Power headroom report
PHY	Physical layer
PIM	Passive Intermodulation
PLMN	Public land mobile network
PMCH	Physical multicast channel
PMI	Precoding matrix indicator
PMIP	Proxy mobile IP
PoC	Push-to-talk over cellular
PRACH	Physical random access channel
PRB	Physical resource block
PS	Packet switched
PSC	Primary synchronization code
P-SCH	Primary synchronization channel
PSS	Primary synchronization signal
PSTN	Packet switched telephone network
PSVT	Packet switched video telephony
PTT	Push-to-talk
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QCI	QoS class identifier
QoS	Quality of service
QPSK	Quadrature phase shift keying
RA	Routing area
RAC	Routing area code
RACH	Random access channel
RAN	Radio access network

RAPID	Random access preamble identifier
RAR	Random access response
RAU	Routing area updating
RB	Resource block
RBG	Resource block group
RDS	RMS delay spread
RE	Resource element
REG	Resource element group
RI	Rank indicator
RIV	Resource indication value
RL	Reverse link
RLC	Radio link control
RLF	Radio link failure
RMS	Root-mean-square
RN	Relay Node
RNC	Radio network controller
RNL	Radio network layer
RNTI	Radio network temporary identifier
ROHC	Robust header compression
ROI	Return On Investment
RPLMN	Registered PLMN
RRC	Radio resource control
RRM	Radio resource management
RS	Reference signal
RV	Redundancy version
SAE	System architecture evolution
SAW	Stop-and-wait
SC-FDM	Single-carrier frequency division multiplexing
SC-FDMA	Single-carrier frequency division multiple access
SCH	Supplemental channel (CDMA2000)
	Synchronization channel (WCDMA)
SCTP	Stream control transmission protocol
SCW	Single code word
SDF	Service data low
SDM	Spatial division multiplexing
SDMA	Spatial division multiple access
SDU	Service data unit
SFBC	Space frequency block code
SFN	System frame number
SGSN	Serving GPRS support node
S-GW	Serving gateway
SI	System information message
SIB	System information block
SINR	Signal to interference noise ratio
SM	Session management
	Spatial multiplexing

SNR	Signal to noise ratio
SOAP	Simple Object Access Protocol
SPOF	Single Point of Failure
SPS	Semi-persistent scheduling
SR	Scheduling request
SRS	Sounding reference signals
SSC	Secondary synchronization code
S-SCH	Secondary synchronization channel
SSS	Secondary synchronization signal
SU-MIMO	Single-user multiple-input–multiple-output
TA	Tracking area
	Timing advance/alignment
TAC	Tracking area code
TAI (_List)	Tracking area identifier (_List)
TAU	Tracking area update
TDD	Time division duplex
TDM	Time division multiplexing
TDMA	Time division multiple access
TFT	Traffic flow template
TPC	Transmit power control
TTI	Transmission time interval
Tx	Transmit
UCI	Uplink control information
UE	User equipment
UL	Uplink
UL-SCH	Uplink shared channel
UMTS	Universal mobile telecommunications system
UP	User plane
UTRA	UMTS terrestrial radio access
UTRAN	UMTS terrestrial radio access network
VAF	Voice Activity Factor
VoIP	Voice over Internet protocol
VoLTE	Voice over LTE
VRB	Virtual resource block
VT	Video telephony
WACC	Weighted Average Cost of Capital
WCDMA	Wideband code division multiple access
WiMAX	Worldwide interoperability for microwave access
X2	The interface between eNodeBs
ZC	Zadoff–Chu