



**Shing-Fong Su**

# **The UMTS Air-Interface in RF Engineering**

**Design & Operation  
of UMTS Networks**



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# The UMTS Air-Interface in RF Engineering: Design and Operation of UMTS Networks

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# **The UMTS Air-Interface in RF Engineering**

## ABOUT THE AUTHOR

**Shing-Fong Su, Ph.D.**, is a distinguished member of the technical staff at Alcatel-Lucent (formerly Lucent Technologies, Inc.). He has been involved in the network design, deployment, and optimization of CDMA, GSM, and UMTS systems in North America, Taiwan, and China. Previously, he was an electrical engineering professor at the University of South Florida. He was also a senior member of the technical staff at GTE Labs. Dr. Su is the holder of seven U.S. patents and the author of over 70 papers in communications and lightwave technology. He also served as a reviewer for many industry publications, including *IEEE Transactions on Communications*, *Journal of Lightwave Technology*, *Applied Optics*, and *Electronics Letters*.

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# Preface

UMTS technology is no doubt one of the top contenders in the arena of third-generation mobile communications. The 3GPP organization has developed and published numerous specifications on UMTS for the telecommunication communities to follow. The 3GPP specifications start with Release 99 and continue on to Release 4, Release 5, Release 6, and beyond. Network equipment and mobile vendors have developed or are developing UMTS equipment and devices complying with the 3GPP specifications in order to ensure the interoperability of different equipment vendors' systems. Currently, many UMTS systems have been deployed in a number of markets worldwide and more are to come in the near future.

The main objective of this book is to provide wireless telecommunication professionals and students with a basic understanding of UMTS air interface and RF engineering. Understanding the UMTS air interface and RF engineering is indispensable for RF system and field engineers to do a good job in planning, designing, deploying, optimizing, operating, and maintaining UMTS networks. Although the UMTS air interface has been described in detail in 3GPP specifications, many engineers and managers find that reading through all the specifications can be impractical. Faced with an explosive amount of detailed information, engineers may not have the time and luxury to absorb all air interface specifications in a comprehensive way and keep up with their daily work. They need a book that explains the key parts of the UMTS air interface in an organized fashion so that they can grasp the air interface concepts easily and quickly. In addition to air interface, many engineers and managers also desire to have a book that can provide them with knowledge in all aspects of RF engineering so that they can do their jobs more efficiently. These are the two main reasons that prompted me to write this book.

This book presents not only theoretical discussions but also engineering practices. This is especially true in the area of RF engineering, where

the material presented is essentially based on my own engineering experience. The integration of both theory and practice provides one-stop shopping for the required knowledge that engineers and managers need for understanding the UMTS air interface and for designing, deploying, optimizing, operating, and maintaining UMTS networks. Aside from being used as a handbook for engineers and managers, this book may be utilized as a reference book for engineering students as well.

As I kept readability and succinctness in mind when writing this book, I omitted many details of the UMTS air interface described in the 3GPP specifications. However, I adopted the same symbols and terminologies defined in the 3GPP specifications to avoid confusion wherever applicable. In addition, some figures, tables, and sentences are extracted from 3GPP TSs and TRs with ETSI's permission and are indicated by "courtesy of ETSI." The following statement applies to all material extracted from 3GPP TSs and TRs: "3GPP™ TSs and TRs are the property of ARIB, ATIS, ETSI, CCSA, TTA, and TTC who jointly own the copyright in them. They are subject to further modification and are therefore provided to you 'as is' for information purposes only. Further use is strictly prohibited."

UMTS may encompass different access technologies. This book only focuses on the UMTS system with a WCDMA access network operating in FDD mode. There are many concepts that apply not only to UMTS technology but also to other technologies. Therefore, UMTS specific terminologies and general terminologies are used interchangeably throughout this book. For example, Node B and base station are used synonymously, as are UE and mobile.

This book contains 16 chapters. Following is a summary of the topics covered in each one:

- Chapter 1 presents a brief introduction of UMTS, including definitions of UMTS, WCDMA evolution, UMTS services, and UMTS network architecture.
- Chapter 2 describes in detail the UMTS basics, including the protocol stack, UMTS signaling, control planes, user planes, UMTS channels and channel mapping, frame timing, system frame number, connection frame number, UE call states, and UE/subscriber identifiers. Chapter 3 briefly introduces the 3GPP organization and UMTS standards, including standard evolution and standard Releases, with emphasis on radio access specifications.
- Chapters 4 to 7 deal with UMTS access stratum, including Radio Resource Control (RRC), Radio Link Control (RLC), Medium Access Control (MAC), and Physical Layer concepts.
- Chapter 8 depicts cell reselection in detail.

- Chapter 9 discusses handover mechanisms, including soft handover, softer handover, and hard handover. Also discussed in this chapter are measurement control and reporting, and the compressed mode.
- Chapter 10 talks about UMTS power control.
- Chapter 11 offers a brief overview of High-Speed Downlink Packet Access (HSDPA).
- Chapter 12 presents WCDMA radio network planning.
- Chapter 13 gives general concepts on WCDMA RF network optimization, including RF network optimization procedures, drive test, and data analysis.
- Chapter 14 describes the application of repeaters and tower-mounted amplifiers in WCDMA systems. It addresses the engineering considerations for the usage of repeaters and tower top amplifiers in WCDMA networks from a practical point of view and provides some guidelines for repeater deployment.
- Chapter 15 discusses intersystem interference, including interference between WCDMA and CDMA2000, between WCDMA and GSM, and between WCDMA and PHS systems.
- Finally, Chapter 16 gives a comparison of WCDMA and CDMA2000. Similarities and differences of the two systems are examined.

*—Shing-Fong Su*



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# Acknowledgments

Many people have helped me in the process of writing this book. Firstly, I would like to thank Sarah Chan. Two years ago, Sarah inspired me to write this book with her suggestion that I should utilize my expertise in the RF engineering field to write a book on UMTS. As my manager, she provided continuous support and encouragement during the past two years. This book would not have been possible without her assistance and the simultaneous support of all the members of the RF engineering group headed by her.

Secondly, I would like to thank Chuck Adelman, Rick Shaw, Gopal Jaisingh, and Talmage Bursh for shepherding this book through the approval process, and my thanks also goes to Paul Mankiewich for granting the final approval. I would also like to thank the European Telecommunications Standards Institute (ETSI) for permitting the usage of many of the figures and tables in the 3GPP specifications.

My colleague, Li Meng, took the time to patiently read the manuscript and to respond with numerous suggestions and corrections. I would like to express my thanks for her contributions. I also thank the anonymous reviewers who provided me with feedback.

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Last but not least, I am indebted to my family. I am profoundly grateful to my wife, Bih-Hwa, for her love and support through the years. Without her encouragement and support of my professional endeavors, I would not have had the capacity and concentration to complete this book in a timely manner.

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# Nomenclature

16-QAM	16-Quadrature Amplitude Modulation
1x-EVDO	1x Evolution Data Optimized
3G	3rd Generation
3GPP	3rd Generation Partnership Project
AC	access class
ACIF	Australian Communications Industry Forum
ACIR	adjacent channel interference power ratio
ACK	acknowledgment
ACLR	adjacent channel leakage power ratio
ACS	adjacent channel selectivity
AI	acquisition indicator
AICH	acquisition indicator channel (physical channel)
AM	acknowledged mode
AMD	acknowledged mode data
AMR	adaptive multi-rate
AN	access network
ARFCN	absolute radio frequency channel number
ARIB	Association of Radio Industries and Business, Japan
ARQ	automatic repeat request
AS	access stratum
ASC	access service class
ASN.1	abstract syntax notation one
ATIS	Alliance for Telecommunications Industry Solutions, North America
AuC	authentication center
AWGN	additive white Gaussian noise
BCCH	broadcast control channel (logical channel)
BCH	broadcast channel (transport channel)
BER	bit error rate
BLER	block error rate
BMC	broadcast/multicast control
BPSK	binary phase shift keying
BS	base station
BSC	base station controller
BSIC	base station identification code
BTS	base transceiver subsystem
BTSD	base station desensitization
BWAF	bandwidth adjustment factor

C-RNTI	cell radio network temporary identity
CBS	cell broadcast service
CC	call control
CCCH	common control channel (logical channel)
CCITT	Consultative Committee on International Telephony and Telegraphy
CCPCH	common control physical channel
CCSA	China Communications Standards Association, China
CCTrCh	coded composite transport channel
CDF	cumulative distribution function
CDMA	code division multiple access
CFN	connection frame number
C/I	carrier-to-interference ratio
CIO	cell individual offset
CK	cipher key
CM	connection management; compressed mode
CN	core network
CPCH	common packet channel (transport channel)
CPICH	common pilot channel (physical channel)
CQI	channel quality indicator
CRC	cyclic redundancy check
CRCI	cyclic redundancy check indicator
CS	circuit switched; PHS base station
CTCH	common traffic channel (logical channel)
Cu	interface for mobile equipment and USIM
CWTS	China Wireless Telecommunications Standard Group
dB	Decibel
D/C	data/control
DCCH	dedicated control channel (logical channel)
DCH	dedicated channel (transport channel)
DGPS	differential global positioning system
DL	downlink
DOFF	DPCH offset
DPCCCH	dedicated physical control channel (physical channel)
DPCH	dedicated physical channel
DPDCH	dedicated physical data channel (physical channel)
DRAC	dynamic resource allocation control
DRX	discontinuous reception
DSCH	downlink shared channel (transport channel)
DS-CDMA	direct spread CDMA
DTCH	dedicated traffic channel (logical channel)
DTX	discontinuous transmission
E	extension bit
EDGE	enhanced data rates for GSM evolution
EFR	enhanced full rate
EIRP	equivalent isotropic radiated power
EM	electromagnetic
EPC	estimated PDU counter
ETSI	European Telecommunications Standards Institute
EVDO	evolution data optimized
FAC	final assembly code

FACH	forward access channel (transport channel)
FBI	feedback indicator bits
FDD	frequency division duplex
FEC	forward error correction
FER	frame error rate
FP	frame protocol
F-FCH	forward fundamental channel
F-PICH	forward pilot channel
F-QPCH	forward quick paging channel
F-SCH	forward supplemental channel
F-SYNCH	forward synchronization channel
FSPL	free space path loss
FTP	file transfer protocol
GERAN	GSM/EDGE radio access network
GGSN	GPRS gateway support node
GMM	GPRS mobility management
GMSC	gateway mobile switching center
GPRS	general packet radio service
GPS	global positioning system
GSA	Global Mobile Suppliers Association, UK
GSM	Global System for Mobile communications
HARQ	hybrid automatic repeat request
HCS	hierarchical cell structure
HE	header extension
HFN	hyper-frame number
HFNI	hyper-frame number indicator
HLR	home location register
HSDPA	high speed downlink packet access
HS-DPCCH	high speed dedicated physical control channel
HS-DSCH	high speed downlink shared channel (transport channel)
HS-PDSCH	high speed physical downlink shared channel (physical channel)
HS-SCCH	high speed shared control channel (physical channel)
HTTP	hyper text transfer protocol
Hz	Hertz
IE	information element
IK	integrity key
IMEI	international mobile equipment identity
IMP	inter-modulation product
IMSI	international mobile subscriber identity
IMT-2000	International Mobile Telephony
IP	internet protocol
IR	incremental redundancy
ISACC	ICT Standards Advisory Council, Canada
ISCP	interference on signal code power
ITU	International Telecommunications Union
Iu	interface for RNC-to-CN communication
Iub	interface for RNC and Node B communication
Iur	interface for RNC-to-RNC communication
kbps	kilobits per second
km	kilometer

ksps	kilosymbols per second
L1	Layer 1
L2	Layer 2
L3	Layer 3
LA	location area
LAC	location area code
LAI	location area identity
LCR TDD	low chip rate time division duplex
LNA	low noise amplifier
MAC	medium access control (protocol layering context); message authentication code (security context)
MAC-b	MAC for broadcast channels
MAC-c/sh	MAC for common and shared channels
MAC-d	MAC for dedicated channels
MAC-hs	HSDPA medium access control
MAC-I	message authentication code for integrity protection
MAP	mobile application part
Mbps	megabits per second
MCC	mobile country code
Mcps	megachips per second
ME	mobile equipment
MHz	megahertz
MIB	master information block
MIMO	multiple input multiple output
MM	mobility management
MNC	mobile network code
MRP	market representation partners
MRW	move receiving window
MS	mobile station
ms or msec	millisecond
MSC	mobile switching center
MSIN	mobile subscriber identification number
MUX	multiplex
NACK	negative acknowledgment
NAS	non-access stratum
NBAP	Node B application part
NIM	noise injection margin
NMSI	national mobile subscriber identity
NMT	Nordic Mobile Telephone
Node B	UMTS base station
OA&M	operations, administration and maintenance
OMC	operation and maintenance center
OTDOA	observed time difference of arrival
OVSF	orthogonal variable spreading factor
P	polling bit
PAD	padding
P-CPICH	primary common pilot channel (physical channel)
P-SCH	primary synchronization channel (physical channel)
P-TMSI	packet temporary mobile subscriber identity
PCA	power control algorithm
PCCC	parallel concatenated convolutional code

PCCH	paging control channel (logical channel)
PCCPCH	primary common control physical channel (physical channel)
PCH	paging channel (transport channel)
PCP	power control preamble
PCPCH	physical common packet channel (physical channel)
PCS	personal communication systems
PDCP	packet data convergence protocol
PDSCH	physical downlink shared channel (physical channel)
PDSN	packet data switching network
PDU	protocol data unit
PHS	personal handy-phone system
PHY	physical layer
PI	page indicator
PICH	paging indicator channel (physical channel)
PLMN	public land mobile network
PN	pseudorandom noise
PO	power offset
PPP	point-to-point protocol
PRACH	physical random access channel (physical channel)
PS	packet switched; PHS mobile
PSC	primary scrambling code
P-SCH	primary synchronization channel
PSTN	public switched telephone network
P-TMSI	packet temporary mobile subscriber identity
QE	quality estimate
QoS	quality of service
QPSK	quadrature phase shift keying
R1	reserved field
RA	routing area
RAB	radio access bearer
RAC	routing area code
RACH	random access channel (transport channel)
RAI	routing area identity
RAN	radio access network
RAND	random number
RAT	radio access technology
RB	radio bearer
R-DCCH	reverse dedicated control channel
R-EACH	reverse enhanced access channel
R-FCH	reverse fundamental channel
R-SCH	reverse supplemental channel
RF	radio frequency
RLC	radio link control
RNC	radio network controller
RNSAP	radio network subsystem application part
RNTI	radio network temporary identity
RRC	radio resource control; root-raised-cosine
RRM	radio resource management
RSCP	received signal code power
RSN	reset sequence number

RSSI	received signal strength indicator
RTP	real time protocol
RTT	round trip time
Rx	receive
SAW	stop and wait
S-CPICH	secondary common pilot channel (physical channel)
S-SCH	secondary synchronization channel (physical channel)
SCCPCH	secondary common control physical channel (physical channel)
SCH	synchronization channel (physical channel)
SDU	service data unit; segmented data unit
SF	spreading factor
SFN	system frame number
SGSN	serving GPRS support node
SIB	system information block
SID	size index
SIR	signal-to-interference ratio
SM	session management
SMS	short message service
SN	sequence number
SRB	signal radio bearer
SS	supplementary services
SSC	secondary scrambling code
SSDT	site selection diversity transmit
STTD	space time transmit diversity
SUFI	superfield
TAC	type approval code
TCP	transmission control protocol
TCTF	target channel type field
TD-SCDMA	time division synchronous code division multiple access
TDD	time division duplex
TF	transport format
TFC	transport format combination
TFCI	transport format combination indicator
TFCS	transport format combination set
TFRC	transport format resource combination
TFRI	transport format resource indicator
TFS	transport format set
TG	transmission gap
TGCFN	transmission gap connection frame number
TGD	transmission gap start distance
TGL	transmission gap length
TGP	transmission gap pattern
TGPL	transmission gap pattern length
TGPRC	transmission gap pattern repetition count
TGPS	transmission gap pattern sequence
TGPSI	transmission gap pattern sequence identifier
TIA	Telecommunications Industries Association, US
TM	transparent mode
TMSI	temporary mobile subscriber identity
TOI	third order intercept

TPC	transmission power control
TRX	transmitter/receiver, also transceiver
TTI	transmission time interval
TTA	Telecommunications Technology Association, Korea
TTC	Telecommunications Technology Committee, Japan.
Tx	transmit
U-RNTI	UTRAN radio network temporary identity
UARFCN	UTRA absolute radio frequency channel number
UDP	user datagram protocol
UE	user equipment
UEA1	UMTS encryption algorithm 1
UIA1	UMTS integrity algorithm 1
UL	uplink
UM	unacknowledged mode
UMTS	Universal Mobile Telecommunications System
URA	UTRAN registration area
USIM	universal subscriber identity module
UTC	coordinated universal time
UTRA	universal terrestrial radio access
UTRAN	UMTS (universal) terrestrial radio access network
Uu	over-the-air interface between the UE and the Node Bs
VLR	visitor location register
VoIP	voice over IP
VSWR	voltage standing wave ratio
WCDMA	wideband code division multiple access



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