

Cambridge University Press

978-1-107-02309-3 - Heterogeneous Cellular Networks: Theory, Simulation and Deployment

Edited by Xiaoli Chu, David López-Pérez, Yang Yang and Fredrik Gunnarsson

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Heterogeneous Cellular Networks

This detailed, up-to-date introduction to heterogeneous cellular networking presents its characteristic features, the technology underpinning it, and the issues surrounding its use.

Comprehensive and in-depth coverage of core topics catalog the most advanced, innovative technologies used in designing and deploying heterogeneous cellular networks, including system-level simulation and evaluation, self-organization, range expansion, cooperative relaying, network MIMO, network coding, and cognitive radio. Practical design considerations and engineering tradeoffs are also discussed in detail, including handover management, energy efficiency, and interference management techniques.

A range of real-world case studies, provided by industrial partners, illustrate the latest trends in heterogeneous cellular network development. Written by leading figures from industry and academia, this is an invaluable resource for all researchers and practitioners working in the field of mobile communications.

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Theory, Simulation and Deployment

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**To those who have enlightened our lives
with love and knowledge**

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Forewords

Gordon Mansfield

Small Cell Forum

My name is Gordon Mansfield, and I currently serve as the elected chairman of the Small Cell Forum. The Forum is an industry body that promotes and drives the wide-scale adoption of small cell technologies to improve coverage, capacity and services delivered by mobile networks. I have many years of experience in the space, having previously served on the Femto Forum board from 2008–2010 and having led a tier one operators small cell effort since 2007. I consider it a great honor to be asked to write the foreword for this very informative book on small cells and heterogeneous networks. The authors are all highly respected researchers in academia and in industry, who have spent years working on the topics covered.

In recent years, small cells have become a very big topic when discussing mobile Internet and the tremendous data growth experienced over the past five years by operators around the globe. When we look at the recent history of data growth, some operators have experienced a 20,000 percent growth in data from 2007–2011. Combine that with the incredible forecast coming from all parts of the industry suggesting 10X and higher growth over the next four to five years, and it becomes clear that new ways to serve this data growth are necessary. We cannot continue to rely on new spectrum and advances in the air interface alone to sustain these types of data growth.

To be clear, small cells are not really new. They have been around for some time to provide capacity within limited amounts of spectrum. However, the solutions that were available up until a few years ago were limited in their functionality and, due to the massive growth in data, expensive to deploy on the scale required today. The high-power base stations in the macro network remain very important to maintain broad umbrella coverage, but, as demand in concentrated areas continue to rise, we will need not only traditional picocells and microcells that exist today but new innovative small cell solutions that allow for densification of networks in a cost-effective and aesthetically appealing way. These will range from femtocells, which have become a mature technology in the past couple of years, to new flavors of picocells and relays that are not yet productized in large numbers. Of course, to tie all of this together, we need software functionality to enable true heterogeneous networks and self-organizing network (SON) capabilities to manage the large increase in nodes within the mobile network of tomorrow.

The authors of this book effectively and insightfully break down the important factors of heterogeneous cellular networks and cover the various types of nodes that may be used. They lay a good technical foundation, and address several of the challenging areas that require focus for heterogeneous cellular networks to become a widespread success. They give the mobile operator several pieces of information that can be useful in helping them decide the best way to evolve their network, from the homogeneous network of today to the heterogeneous network of tomorrow.

As the topic of small cells and heterogeneous networks is at the forefront of many mobile operators’ decision-making today, I am happy to see a book like this, which not only lays the foundation, but also provides many details on things that should be considered.

Gordon Mansfield
Chairman, Small Cell Forum

Alan Stidwell

Orange Labs, France Telecom

My name is Alan Stidwell, and I am Senior Technical Specialist within Wireless Technology Evolution at Orange Labs, France Telecom. My main role is to assess the performance benefits coming from future radio access technology evolutions (from two years +), to develop mid/long-term radio access network strategies, and to support work on radio access networks in 3GPP.

Until recently, most mobile network operators have been very focused on delivering customer performance needs mainly through macrocellular based deployments. This strategy is starting to be tested by the rapid increase in traffic volumes experienced during the last two to three years, which is expected to continue, and which are causing operators to deliver additional capacity at an accelerated rate compared to previous years. Additional capacity can be delivered by adding new technologies in additional spectrum on existing macrocell sites. This applies even for the early LTE deployments, primarily because this is the most cost-effective way to achieve coverage for a new technology whilst at the same time adding considerable capacity. Such deployments also bring big initial improvements in user experience because the early adopters will have the benefits of a largely unloaded network, thus amplifying the perceived performance compared to legacy 3G networks. However, it takes time for users to migrate their devices to LTE and in the meantime the traffic is still growing on the existing 3G network, which calls for a different strategy in order to avoid disappointing users on the legacy network. A primary way to achieve this additional capacity on legacy networks is through deployment of small cells, using legacy technologies that are in widespread use in existing devices. Furthermore, if the traffic predictions are correct, then it will not take too long before early LTE macrocell networks also become overloaded with a corresponding drop in user experience. Spectrum is also a finite and expensive resource, and therefore a continuing expansion of capacity in the macrocell domain alone may

not be compatible with future capacity needs. In addition, macrocells are not necessarily the most cost- or energy-efficient way to deliver additional capacity in areas where there are predominantly non-uniformly distributed (or clustered) users. The need to maintain a reasonable user experience with this expected ongoing growth in traffic, whilst at the same time respecting the limits on spectrum, is therefore stimulating the whole industry to develop small cell solutions for both the new and legacy technologies.

These changes are happening very fast, and there is very little published on small cells and HetNets so far. This book is therefore very timely, and the way it comprehensively deals with all the relevant topics will appeal to many colleagues in all areas of the mobile industry who wish to get up to speed on this very important and fast-evolving technological change in network topology. Even experts and people with some prior knowledge in the field should find value in it, since it pulls together in one place a lot of valuable information and reference material.

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978-1-107-02309-3 - Heterogeneous Cellular Networks: Theory, Simulation and Deployment

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Frontmatter

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Preface

Driven by a new generation of wireless user equipments and the proliferation of bandwidth-intensive applications, mobile data traffic and network load are increasing in unexpected ways, and are straining current cellular networks to a breaking point. In this context, heterogeneous cellular networks, which are characterized by a large number of network nodes with different transmit power levels and radio frequency coverage areas, including macrocells, remote radio heads, microcells, picocells, femtocells and relay nodes, have attracted much momentum in the wireless industry and research community, and have also gained the attention of standardization bodies such as the *3rd Generation Partnership Project* (3GPP) LTE/LTE-Advanced and the *Institute of Electrical and Electronics Engineers* (IEEE) *Mobile Worldwide Interoperability for Microwave Access* (WiMAX).

The impending worldwide deployments of heterogeneous cellular networks bring about not only opportunities but also challenges. Major technical challenges include the co-existence of various neighboring and/or overlapping cells, intercell interference and mobility management, backhaul provisioning, and self-organization that is crucial for efficient roll-outs of user-deployed low-power nodes. These challenges need to be addressed urgently to make the best out of heterogeneous cellular networks. This asks for a thorough revisit of contemporary wireless network technologies, such as network architecture and protocol designs, spectrum allocation strategies, call management mechanisms, etc. There is also an urgent need in the wireless industry, academia and even end-users to better understand the technical details and performance gains that heterogeneous cellular networks would make possible.

Heterogeneous Cellular Networks – Theory, Simulation and Deployment provides a complete and thorough exposition of heterogeneous cellular networks, with a delicate balance between theory and practice. It contains cutting-edge tutorials on the technical and theoretical foundations upon which heterogeneous cellular networks are built, while also providing high-level overviews of standardization activities that are informative to readers of all backgrounds. The book is written by researchers currently leading the investigations on heterogeneous cellular networks, covering a wide spectrum of topics such as simulation and evaluation models, advanced radio resource management, self-organization, mobility and handover issues, cooperative communications, network *multiple-input multiple-output* (MIMO) techniques, network coding, cognitive radio, energy efficiency, etc.

The book is organized into 14 chapters. Chapter 1 provides the background information necessary for understanding the theoretical and technical foundations of heterogeneous cellular networks, as well as discussions of technical challenges in deploying heterogeneous cellular networks, and serves as a summary of the rest of the book.

Chapter 2 describes the process of building a radio propagation model, and provides a detailed review of different radio propagation modeling techniques, including empirical models, deterministic models, semi-deterministic models and hybrid models. The tradeoff between radio channel modeling accuracy and complexity is discussed. Moreover, this chapter identifies the need and requirements for new radio propagation modeling tools that are able to operate in heterogeneous cellular network scenarios, which may involve both indoor and outdoor environments.

In Chapter 3, we look into important issues in system-level simulations for heterogeneous cellular networks. We review different kinds of system-level simulation, and compare dynamic system-level simulations with static ones. Intricate modeling issues, such as wrap-around, shadowing, multi-path fading, antenna patterns, diversity combining and signal quality modeling, are discussed. Traffic and mobility modeling is also described. Simulation setups for heterogeneous cellular networks from the perspective of 3GPP are illustrated, taking into account features of heterogeneous cellular network nodes and channel modeling, and covering macro-pico, macro-femto and macro-relay scenarios.

Access control enables flexible installation and operation of low-power nodes for different deployment scenarios. Chapter 4 provides an in-depth description of access control in heterogeneous cellular networks from the perspectives of the core network, radio access network and user equipments. The benefits and tradeoff of different access control mechanisms are analyzed through numerical simulations using various performance metrics, such as the percentage of offloaded user equipments, as well as cell-average and cell-edge data throughputs. Moreover, the access control enhancements standardized during LTE Releases 8, 9 and 10 are discussed.

In Chapter 5, we first provide an overview of stochastic models where the locations of network nodes can be modeled following a *Poisson point process* (PPP) or a hardcore point process. Then, motivated by the accuracy and tractability of PPP network models, we present a stochastic-geometry-based two-tier network framework, and study the effects of spectrum allocation and different access schemes on the link reliability of each tier of a heterogeneous cellular network and on the network area spectral efficiency. We investigate both disjoint and joint subchannel allocation, where the two tiers are assigned disjoint sets of subchannels or share the whole spectrum, respectively. Moreover, we quantify the enhancement in a user equipment's link reliability when it can hand over from the macrocell to the closest femtocell, and analyze the resulting benefits to the network throughput. The proposed framework also allows us to generalize the results to multi-tier heterogeneous cellular networks.

Self-organizing networks (SONs) provide means to facilitate network and service management, while supporting radio network robustness and optimized coverage and capacity. SON functionalities are commonly divided into self-configuration, self-optimization

and self-healing. These are especially important to heterogeneous cellular networks due to the increasing number of nodes that need to be managed. Self-configuration enables smooth introduction of low-power nodes into an existing macrocell deployment. Continuous self-optimization and self-healing ensure that the low-power nodes are able to provide the intended capacity without requiring significant human management and monitoring efforts. In Chapter 6, we provide relevant insights about SON for heterogeneous cellular networks, with a main focus on 3GPP LTE, and discuss key performance monitoring aspects. Different deployment options are described in relation to the 3GPP management architecture. The associated 3GPP SON feature requirements and signaling support are also described together with 3GPP specification references.

Chapter 7 reviews intercell interference problems and interference management techniques for heterogeneous cellular networks. Some simulation results are used to demonstrate the downlink/uplink coverage imbalance issues in heterogeneous deployments. Range expansion of small cells, cell-selection methods and intercell interference coordination techniques are discussed, including mechanisms recently proposed in the 3GPP LTE. The dedicated focus is on frequency-domain, power-based and time-domain interference management. Moreover, performance assessments and comparisons are provided through system-level simulations, indicating some design guidelines for dynamic interference management.

Interference management becomes even more challenging if there are restrictions in access mechanisms and internode signaling, for example in femtocells. Chapter 8 looks into uncoordinated femtocell deployments, and self-organizing femtocell networks are discussed, from the perspectives of the Small Cell Forum. With less strict backhaul requirements as compared with other heterogeneous cellular network nodes, femtocell backhaul time synchronization becomes especially critical and is paid special attention. Moreover, power-based, antenna-based and frequency-domain techniques for interference mitigation in uncoordinated femtocells are reviewed in detail.

Chapter 9 provides an overview of mobility robustness, handover management and *mobility load balancing* (MLB) in LTE/LTE-Advanced systems, and develops *mobility robustness optimization* (MRO) algorithms under both *Radio Resource Control* (RRC) connected and idle modes. Under the RRC connected mode, we introduce the hard handover procedure in LTE and the MRO use case, and propose an MRO scheme to assign different handover hysteresis values for user equipment traveling at different velocities. Under the RRC idle mode, we introduce cell selection/reselection procedures, and propose a negotiation mechanism to solve the *cell-specific reference symbol* (CRS) parameter mismatch between neighboring cells and the mismatch between CRS and handover parameters. Specifically for heterogeneous cellular networks, we identify the technical challenges in mobility management, evaluate the mobility performance under 3GPP Release 10 enhanced *intercell interference coordination* (ICIC) features, and propose a mobility-based ICIC scheme.

In Chapter 10, we first review and analyze the performance of *amplify-and-forward* (AF) relay, *demodulate-and-forward* (DMF) relay and *decode-and-forward* (DCF) relay, and propose a link adaptation scheme for the DMF relay. Then, the 3GPP LTE-Advanced relay system architectures in heterogeneous cellular networks are introduced. In order to

fully explore the capacity of cooperative relaying, the emerging *estimate-and-forward* (EF) relay and joint network-channel coding are presented together with a new link adaptation scheme.

Network MIMO, also known as *multi-cell processing* (MCP) or *coordinated multi-point* (CoMP), combines MIMO and cooperation techniques to provide new means to manage interference more intelligently, while increasing the spectral efficiency. In Chapter 11, we first analyze the problems with existing *single-cell processing* (SCP), review different types of MCP and introduce application scenarios of MCP for heterogeneous cellular networks. Afterwards, we demonstrate how MCP together with MIMO transmit beamforming techniques and power control can mitigate *intercarrier interference* (ICI) to achieve a better tradeoff between system throughput and user fairness in heterogeneous cellular networks. Practical implementation issues such as backhaul requirements, base station clustering and *channel state information* (CSI) acquisition are discussed, and future research directions are outlined.

Network coding is a technique that smartly controls the interference from different source nodes to improve the overall network performance. Overlaying network coding techniques upon existing cellular networks provides a simple and economical way to tremendously enhance the network performance without too many hardware replacements. In Chapter 12, we first explain the fundamentals of network coding and its state-of-the-art developments. Then, we give coding-gain upper bounds with and without practical geometry considerations, as well as illustrative examples to show the performance gains and effectiveness of applying simple network coding solution to heterogeneous cellular networks. Following that, we analyze the efficiency and reliability performance of network coding using a two-way relay-aided X network. Finally, we introduce a low-complexity and distributed coding solution construction method that is ideal for heterogeneous cellular networks.

Dynamic spectrum access (DSA) or *cognitive radio* (CR) has the potential to provide significant benefits and simple solutions to overcome many of the challenges faced by heterogeneous cellular networks. Chapter 13 presents a detailed overview of the functionalities and techniques associated with DSA/CR technologies, including methods to acquire spectrum awareness, select the appropriate frequency of operation and share spectrum opportunities in a non-interfering manner, and explores the potential application of DSA/CR concepts and techniques in heterogeneous cellular networks. Several practical scenarios are explored. Various implementation alternatives along with the corresponding pros and cons are discussed. Related cross-layer issues and design tradeoffs are investigated. Finally, recent standardization efforts aimed at developing new systems based on DSA/CR principles and including DSA/CR capabilities in existing standards are reviewed.

Making cellular networks green would have a tangible positive impact on reducing the carbon footprint of *information communication technology* (ICT), and achieve a long-term profitability for mobile service operators. Chapter 14 focuses on heterogeneous cellular network architectures and their potential to deliver improved performance at reduced energy and cost consumption levels. In particular, the chapter examines the fundamental tradeoffs between performance and energy consumption, recently proposed

heterogeneous cellular network architectures, dynamic base station designs, advanced transmission schemes, hardware improvements, and cross-layer integration solutions. We also present a comprehensive survey of latest green techniques for homogeneous and heterogeneous cellular networks with discussions of their merits and demerits. Moreover, recent research projects for green cellular networks are reviewed, and a taxonomy of green metrics is summarized.

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Acronyms

3GPP	3rd Generation Partnership Project
4G	fourth generation
ABS	almost blank subframe
AF	amplify-and-forward
AM	acknowledged mode
AMC	adaptive modulation and coding
ANR	Automatic Neighbor Relation
AoA	angle of arrival
AoD	angle of departure
AP	access point
APP	a posteriori probability
ARCF	automatic radio configuration data handling function
ARQ	Automatic Repeat reQuest
AWGN	additive white Gaussian noise
BCJR	Bahl–Cocke–Jelinek–Raviv
BER	bit error rate
BLER	block error rate
BPSK	binary phase-shift keying
BS	base station
BSP	binary space partitioning
CA	closed access
CAPEX	capital expenditure
CAS	cluster angular spread
CCC	common control channel
CCO	coverage and capacity optimization
CDF	cumulative distribution function
CDMA	code division multiple-access
CDS	cluster delay spread
CFL	Courant–Friedrichs–Lewy
CIO	cell individual offset
CIR	channel impulse response
CM	configuration management
CN	core network

CoMP	coordinated multi-point
CPC	cognitive pilot channel
CPE	customer premises equipment
CQI	channel quality indicator
CR	cognitive radio
CRC	cyclic redundancy check
CRE	cell range expansion
C-RNTI	cell radio network temporary identifier
CRS	cell-specific reference symbol
CSCC	common spectrum coordination channel
CSG	closed subscriber group
CSG ID	CSG identity
CSI	channel state information
CSIR	receiver-side channel state information
CSO	cell selection offset
CTS	Clear-to-Send
DAB	Digital Audio Broadcasting
DAS	distributed antenna system
DCF	decode-and-forward
DCH	dedicated channel
DCM	directional channel model
DECT	Digital Enhanced Cordless Telecommunications
DeNB	donor eNB
DFS	Dynamic Frequency Selection
DHCP	Dynamic Host Configuration Protocol
DL	downlink
DM	domain manager
DMC	dense multi-path componens
DMF	demodulate-and-forward
DNS	Domain Name System
DMT	diversity and multiplexing tradeoff
DoA	direction-of-arrival
DoD	direction-of-departure
DPC	dirty-paper coding
D-QDCR	Distributed QoS-based Dynamic Channel Reservation
DS	downstream
DSA	dynamic spectrum access
DSL	digital subscriber line
DSP	digital signal processor
DVB	Digital Video Broadcasting
E2E	end-to-end
ECGI	Evolved Cell Global Identifier
EESM	exponential effective SINR mapping
EF	estimate-and-forward

EGC	equal gain combining
EM	element manager
eNB	evolved NodeB
EoA	elevation of arrival
EoD	elevation of departure
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-RAB	E-UTRAN radio access bearer
ESF	even subframe
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved UTRA
E-UTRAN	Evolved UTRAN
FAP	femtocell access point
FCC	Federal Communications Commission
FCFS	first come first served
FCI	failure cell ID
FD	frequency domain
FDD	frequency division duplexing
FDTD	finite-difference time domain
FER	frame error rate
FGW	femto gateway
FIFO	first in first out
FM	fault management
FPGA	field-programmable gate array
FTP	File Transfer Protocol
FUE	femtocell user equipment
GERAN	GSM EDGE Radio Access Network
GNSS	global navigation satellite system
GPS	Global Positioning System
GSCM	geometry-based stochastic channel models
GSM	Global System for Mobile Communications
GTD	geometry theory of diffraction
GTP	GPRS Tunnel Protocol
HA	hybrid access
HARQ	hybrid automatic repeat request
HCN	heterogeneous cellular network
HDTV	high-definition television
HeNB	Home evolved NodeB
HGW	home gateway
HII	high-interference indicator
HMS	HNB/HeNB management system
HNB	Home NodeB
HO	handover
HOF	handover failure

HOM	handover hysteresis margin
HRD	horizontal reflection diffraction
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HUE	home user equipment
IC	interference cancellation
ICI	intercarrier interference
ICIC	intercell interference coordination
ICT	information communication technology
ID	identifier
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IIR	infinite impulse response
IMEI-TAC	International Mobile Equipment Identity Type Allocation Code
IMT	International Mobile Telecommunications
InH	indoor hotspot
IP	Internet Protocol
IRC	interference rejection combining
ISD	intersite distance
ITU	International Telecommunication Union
JFI	Jain’s fairness index
KPI	key performance indicator
L1	layer one
L2	layer two
L3	layer three
LLR	log-likelihood ratio
LMDS	Local Multipoint Distribution Service
LMMSE	linear minimum mean square error
LOS	line of sight
LPN	low-power node
LR	likelihood ratio
LSP	large-scale parameter
LTE	Long Term Evolution
LTE/SAE	Long Term Evolution/System Architecture Evolution
LUT	lookup table
MAC	medium access control
MBS	macrocell base station
MCC	mobile country code
MCM	multi-carrier modulation
MCP	multi-cell processing
MCS	modulation and coding scheme
MDT	minimization of drive tests
MIB	Master Information Block
MIESM	mutual information effective SINR mapping

MIMO	multiple-input multiple-output
MISO	multiple input single output
ML	maximum likelihood
MLB	mobility load balancing
MME	Mobility Management Entity
MMSE	minimum mean square error
MNC	mobile network code
MPC	multi-path components
MR	measurement report
MRC	maximal ratio combining
MR-FDPF	multi-resolution frequency-domain ParFlow
MRO	mobility robustness optimization
MUE	macrocell user equipment
NAS	non-access stratum
NAV	Network Allocation Vector
NB	NodeB
NE	network element
NGMN	Next Generation Mobile Networks
NLOS	non-line-of-sight
NM	network management
NMS	network management system
NRT	neighbor relation table
NTP	Network Time Protocol
OA	open access
OAM	operation, administration, and maintenance
OCXO	oven controlled oscillator
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OI	overload indicator
OPEX	operational expenditure
OSF	odd subframe
OSI	Open Systems Interconnection
P2MP	point to multi-point
P2P	point to point
PBCH	primary broadcast channel
PCI	physical layer cell identity
PDCP	Packet Data Convergence Protocol
PDF	probability density function
PDSCH	physical downlink shared channel
PeNB	pico evolved NodeB
PGW	Packet Data Network Gateway
PH	power headroom
PHY	physical
PLMN	public land mobile network

PML	perfectly matched layer
PPP	Poisson point process
PRB	physical resource block
PSC	primary scrambling code
PSS	primary synchronization signal
PTP	Precision Time Protocol
PUE	picocell user equipment
QAM	quadrature amplitude modulation
QCI	QoS class identifier
QoS	quality of service
QPSK	quadrature phase-shift keying
RAB	Radio Access Bearer
RACH	random access channel
RAN	radio access network
RAT	radio access technology
RAXN	relay-aided X network
RB	resource block
RCI	re-establish cell ID
RE	range expansion
REB	range expansion bias
RF	radio frequency
RFC	Request for Comments
RIM	RAN information management
RLC	Radio Link Control
RLF	radio link failure
RMSE	root mean square error
RN	relay node
RNC	Radio Network Controller
RNL	radio network layer
RNS	Radio Network Subsystem
RNTP	relative narrowband transmit power
RPSF	reduced-power subframe
RRC	Radio Resource Control
RRH	remote radio head
RRM	radio resource management
RS	reference signal symbol
RSC	Recursive Systematic Convolutional
RS-CS	resource-specific cell selection
RSQ	reference signal quality
RSRP	reference signal received power
RSRQ	reference signal received quality
RSS	reference signal strength
RSSI	reference signal strength indicator
RTS	Request-to-Send

S1AP	S1 Application Protocol
S1-MME	S1 for the control plane
S1-U	S1 for the user plane
SAE	System Architecture Evolution
SAEGW	System Architecture Evolution Gateway
SAS	spectrum allocation server
SBS	super base station
SCC	Standards Coordinating Committee
SCM	spatial channel model
SCP	single-cell processing
SCTP	Stream Control Transmission Protocol
SDMA	space-division multiple access
SDR	software defined radio
SE	spectral efficiency
SEF	soft symbol estimation and forward
SFBC	space frequency block coding
SGW	Serving Gateway
SI	system information
SIB	system information block
SIB1	System Information Block Type 1
SIB4	System Information Block Type 4
SIC	successive interference cancellation
SIM	subscriber identity module
SIMO	single input multiple output
SLA	service level agreement
SN	serial number
SNTP	Simple Network Time Protocol
SINR	signal to interference plus noise ratio
SIR	signal to interference ratio
SISO	single-input single-output
SLAC	stochastic local area channel
SLNR	signal to leakage interference and noise ratio
SNR	signal to noise ratio
SOCP	second-order cone programming
SON	self-organizing network
SoT	saving of transmissions
SPS	spectrum policy server
SSMA	spread spectrum multiple access
SSS	secondary synchronization signal
STBC	space-time block coding
TA	timing advance
TAC	tracking area code
TAI	tracking area identity
TCE	Trace Collection Entity

TCoSH	Triggering Condition of Self-Healing
TCP	Transmission Control Protocol
TCXO	temperature controlled oscillator
TDD	time division duplexing
TDM	time division multiplexing
TDMA	time division multiple access
TEID	tunnel endpoint identifier
TNL	transport network layer
TPC	Transmit Power Control
TR	transition region
TSG	Technical Specification Group
TTT	time-to-trigger
TU	Typical Urban
TV	television
TWXN	two-way exchange network
UE	user equipment
UL	uplink
UMa	urban macrocell
UMTS	Universal Mobile Telecommunication System
US	upstream
UTD	uniform theory of diffraction
UTRA	UMTS Terrestrial Radio Access
UTRAN	UMTS Terrestrial Radio Access Network
UWB	ultra-wide band
VD	vertical diffraction
VeNB	virtual eNB
VoIP	voice over IP
VR	visibility region
WCDMA	wideband code division multiple access
WG	working group
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WNC	wireless network coding
WLAN	wireless local area network
WRAN	wireless regional area network
X2AP	X2 Application Protocol