# WCDMA (UMTS) DEPLOYMENT HANDBOOK

## Planning and Optimization Aspects

Editors

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*All of QUALCOMM Incorporated*
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John Wiley & Sons, Ltd

Published in 2006 by John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester,
West Sussex PO19 8SQ, England

Telephone (+44) 1243 779777

Email (for orders and customer service enquiries): cs-books@wiley.co.uk
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Jossey-Bass, 989 Market Street, San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH, Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 42 McDougall Street, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 6045 Freemont Blvd, Mississauga, ONT, L5R 4J3, Canada

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***British Library Cataloguing in Publication Data***

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

ISBN-13: 978-0-470-03326-5 (HB)
ISBN-10: 0-470-03326-6 (HB)

Typeset in 10/12pt Times by Laserwords Private Limited, Chennai, India.
Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham, England.
This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

# Contents

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# Foreword

Mobile wireless communications has already dramatically affected our lives, and will continue to do so as usage, services, and coverage rapidly expand with the adoption of the Third Generation of cellular wireless, and the transition to Internet-protocol-based networks.

First Generation cellular networks used analog FM and circuit switching. Despite low voice capacity, uneven quality, limited roaming, and bulky, expensive handsets with limited battery life, the rapid increase of voice subscribers necessitated the adoption of digital transmission technology.

Second Generation (2G) networks, including TDMA-based GSM, PDC, IS-54, and CDMA-based IS-95, allowed rapid expansion of voice subscribers and the introduction of some data services, including short message service (SMS). These Second Generation digital technologies featured advanced coding and modulation, offering greater voice capacity and quality, and supporting digital control channels. The result? More robust and secure signals, smaller and lower-power handsets, enhanced roaming, and a rapid expansion of subscribers worldwide. Even with the limited data capabilities of 2G technology, it became clear that a next generation of cellular networks should focus on even greater capacity, high speed data, and increased reliance on packet switching.

Third Generation (3G) wireless, encompassing three forms of CDMA–CDMA2000®, including 1X and EV-DO; WCDMA, also called UMTS and 3GSM; and most recently TD-SCDMA–has been introduced by many operators and is rapidly gaining subscribers. Both plug-in cards and integral modems are supporting broadband mobile communications directly to laptops. An abundance of powerful handsets are now reaching the market, which support a wide variety of services including music, streamed and stored video, multiplayer games, multiparty instant messaging, and location-based services.

Such growth in usage and applications poses great challenges for the network operators, test equipment vendors, infrastructure manufacturers, and the technical staff that plan, deploy, and operate these networks. This book focuses on the knowledge needed to effectively deploy Wideband CDMA (WCDMA) networks, much of which has been either publicly unavailable or widely scattered across various journals and other sources. In gathering and distilling this knowledge in a readable and coherent form, the authors have achieved their goal of further speeding the deployment and optimization of WCDMA networks.

Third Generation cellular networks will enhance our lives in many ways, rapidly reaching every part of the world and supporting education, business, entertainment, health, and government. The demand for knowledgeable practitioners will continue to grow. This book should provide welcome assistance.

We have come a long way. I look forward to the excitement of further rapid change.

**Irwin Mark Jacobs**
Chairman of the Board
QUALCOMM Incorporated

# Preface

In our day-to-day activities, as part of the Engineering Services Group of QUALCOMM®, we consult with network operators throughout the world. In working with them, we have realized that operators repeatedly face the same four challenges: improving RF optimization, properly tuning system parameters, increasing the reliability of inter-system transitions, and providing better indoor coverage. These issues, among others, cannot be resolved simply by studying the communication standard; consequently, they have not been widely addressed in the literature.

In this book, using the experience we have gained from performing many network assessments, we focus on the day-to-day tasks and real world choices that confront operators. We have chosen to minimize paraphrasing of the standard. This is not to say that we disregard the ample documentation written by the Third Generation Partnership Project (3GPP), also known as the standard. We do refer to the standard throughout this book but rather than present its concepts in a dry manner, we introduce only the sections that readers can use to deepen their knowledge on specific topics. We selected these topics to help network planners and optimization engineers make a better transition from GSM to WCDMA while understanding how to perform the required tasks.

This volume attempts to provide as many answers as possible to the complex questions that planners or engineers encounter in their daily activities. As we were writing, we had to make difficult choices about what to include. Without these choices, of course, we would still be writing. Here are the basic questions that we tried to answer in each chapter:

- **Introduction to UMTS networks.** What nodes are necessary in a WCDMA network? What are their basic functions? What is WCDMA anyway? What differentiates WCDMA from other technologies, such as GSM? What are the key terms and concepts of the technology?
- **RF planning and optimization.** What is a typical Link Budget for the different services offered in WCDMA? Is the Downlink or the Uplink limiting? What are the main factors that determine the coverage? How can the coverage of a WCDMA network be qualified?
- **Capacity planning and optimization.** What is the capacity of a WCDMA cell? How does soft handover affect the capacity of a WCDMA network? How do the different services affect the overall capacity? How can the capacity of the network be maximized? Will microcells affect the capacity of the network?
- **Initial parameter settings.** What are the most important parameters to focus on? What is a good starting point for each parameter? How can you verify the values that are broadcast, and where?
- **Service optimization.** How should the optimization process be started? What are the basic procedures that will affect all services? What should you look for to resolve

typical failures? What differs from one service to another? Do any parameters apply only to particular services?

- **Inter-system planning and optimization.** Why rely on other systems? When should you start looking at inter-system issues? What parameters are involved in inter-system changes? What are good starting points for their respective settings?
- **HSDPA.** What is HSDPA? What advantages does it offer compared to a WCDMA (Release 99) network? How does it differ? How and where should HSDPA be deployed? What parameters are available in HSDPA? How do these parameters affect the coverage and capacity of the entire network?
- **Indoor coverage.** Why is indoor coverage different? When should indoor coverage be provided? How can it be achieved and optimized?

By the time you have read this book, you will no doubt be ready to ask several more questions. Hopefully, with the aid of this book, you will have the skills to find the answers you need.

# Acknowledgments

Writing a book of this scope is a major undertaking, one that perhaps cannot be fully appreciated by those who have not wrestled with it. It cannot be achieved without a great deal of help. Adequately acknowledging all the people who have assisted us is difficult, even more so when an entire team has contributed to the effort, even if indirectly. With that in mind, we would like to acknowledge the entire Engineering Services Group of QUALCOMM Incorporated. In particular, we would like to acknowledge the initiators of this project: Dan Agre, Steve Anderson, Richard Costa, and Thomas Erickson. We would also like to thank those who have contributed by reviewing the material, within QUALCOMM and beyond: Jay Dills, Mauricio Guerra, Tony Guy, Pat Japenga, Ben Miller, Mukesh Mittal, Peter Rauber, Mustafa Saglam, Salil Sawhney, and Ralf Weber. Finally, we apologize to all of those we may have neglected to mention here.

# Acronyms

| | |
|---|---|
| 1xEV-DO | Code Division Multiple Access technology compliant with revision 0 of the IS-856 standard, Evolution-Data Optimized of CDMA2000 1X |
| 2-D | Two-Dimensional |
| 2G | Second Generation |
| 3-D | Three-Dimensional |
| 3G | Third Generation |
| 3GPP | Third Generation Partnership Project |
| ACK | ACKnowledge |
| ACLR | Adjacent Channel Leakage Ratio |
| AGC | Automatic Gain Control |
| AICH | Acquisition Indicator Channel |
| AM | Acknowledged Mode |
| AM | Amplitude Modulation |
| AMC | Adaptive Modulation and Coding |
| AMR | Adaptive Multirate |
| ANSI | American National Standards Institute |
| AS | Access Stratum |
| AS | Active Set |
| ASET | Active Set |
| ASN.1 | Abstract Syntax Notation One |
| ASU | Active Set Update |
| ASUC | Active Set Update Complete |
| ATM | Asynchronous Transfer Mode |
| AuC | Authentication Center |
| AUTN | Authentication Token |
| AWGN | Additive White Gaussian Noise |
| BCCH | Broadcast Control Channel |
| BCH | Broadcast Channel |
| BDA | Bidirectional Amplifier |
| BHCA | Busy Hour Call Attempts |
| BLE | Block Error |
| BLER | Block Error Rate |
| BMC | Broadcast/Multicast Control |
| BPL | Building Penetration Loss |
| BS | Base Station |
| BSC | Base Station Controller |
| BSIC | Base Station Identification Code |
| BSS | Base Station sub-System |
| BTS | Base Transceiver Station |

| | |
|---|---|
| CC | Call Control |
| CCCH | Common Control Channel |
| CCTrCh | Coded Composite Transport Channel |
| CDMA | Code Division Multiple Access |
| CDMA2000 1X | Code Division Multiple Access technology compliant with revision 0 or later of IS2000 standard |
| CE | Channel Element |
| CELL_DCH | Basic Connected state following a successful call origination, or termination |
| CFN | Connection Frame Number |
| CIO | Cell Individual Offset |
| cm | centimeters |
| CM | Connection Management |
| CM | Compressed Mode |
| CN | Core Network |
| CPCH | Common Packet Channel |
| CPICH | Common Pilot Channel |
| CPICH_$E_c/N_o$ | Pilot channel quality energy per chip over total received power spectral density |
| CPICH_RSCP | Receive signal code power of the Pilot channel |
| CQI | Channel Quality Indicator |
| CRC | Cyclic Redundancy Check |
| CS | Circuit Switched |
| CTCH | Common Traffic Channel |
| DAS | Distributed Antenna System |
| dB | Decibel |
| dBc | Decibels below carrier power |
| dBi | Decibels Isotropic |
| dBm | Decibel referenced to 1 milliwatt |
| DCCH | Dedicated Control Channel |
| DCH | Dedicated Channel |
| DCR | Dropped Call Rate |
| DCS1800 | Digital Cellular Standard for 1800 MHz band |
| DL | Downlink |
| DPCCH | Dedicated Physical Control Channel |
| DPCH | Dedicated Physical Channel |
| DPDCH | Dedicated Physical Data Channel |
| DRAC | Dynamic Resource Allocation Control |
| DRX | Discontinuous Reception |
| DSCH | Downlink Shared Channel |
| DTCH | Dedicated Traffic Channel |
| DTX | Discontinuous Transmission |
| E1 | European (CEPT) standard data rate of 2.048 Mbps |
| $E_b/N_t$ | Energy per bit over the effective noise power spectral density |
| $E_c/I_{or}$ | Energy per bit over the total transmit power spectral density |
| $E_c/N_o$ | Energy per chip over total received power spectral density |

| | |
|---|---|
| EDGE | Enhanced Data rates for GSM Evolution |
| EFR | Enhanced Full Rate |
| EIR | Equipment Identity Register |
| EIRP | Effective Isotropically Radiated Power |
| EMR | Electromagnetic Radiation |
| ERP | Effective Radiated Power |
| ETSI | European Telecommunications Standards Institute |
| FACH | Forward Access Channel |
| FAF | Floor Attenuation Factor |
| FDD | Frequency Division Duplex |
| FDMA | Frequency Division Multiple Access |
| FEC | Forward Error Correction |
| FPLMTS | Future Public Land Mobile Telecommunication Systems |
| FTP | File Transfer Protocol |
| G | Geometry |
| Gbyte | Gigabyte |
| GERAN | GSM/EDGE Radio Access Network |
| GGSN | GPRS Gateway Support Node |
| GHz | GigaHertz |
| GIS | Geographic Information System |
| GMM | GPRS Mobility Management |
| GMSC | Gateway Mobile Switching Center |
| GoS | Grade of Service |
| GPRS | General Packet Radio Service |
| GPRS-CN | General Packet Radio Service, Core Network |
| GPS | Global Positioning System |
| GSM | Global System for Mobiles |
| GSM900 | Global System for Mobile communication operating in the 900 MHz band |
| HARQ | Hybrid Automatic Repeat Request |
| HCS | Hierarchical Cell Structure |
| HLR | Home Location Register |
| HO | Handover |
| HORF | Handover Reduction Factor |
| HPA | High Power Amplifier |
| HPSK | Hybrid Phase Shift Keying |
| HSDPA | High Speed Downlink Packet Access |
| HS-DPCCH | High Speed Dedicated Physical Control Channel |
| HS-DSCH | High Speed Downlink Shared Channel |
| HS-SCCH | High Speed Shared Control Channel |
| HS-PDSCH | High Speed Physical Downlink Shared Channel |
| HTTP | HyperText Transfer Protocol |
| Hz | Hertz |
| IAF | IntrA-Frequency |
| IC | Integrated Circuit |
| IE | Information Elements |

| | |
|---|---|
| IEEE | Institute of Electrical and Electronic Engineers |
| IEF | IntEr-Frequency |
| IMT-2000 | International Mobile Telecommunications-2000 |
| $I_{oc}/\hat{I}_{or}$ | Ratio of other-cell interference to same-cell received power density |
| $I_{oc}/N_o$ | Ratio of other-cell interference total received power spectral density |
| IP | Internet Protocol |
| IR | Incremental Redundancy |
| IRAT | Inter-Radio Access Technology |
| IS-95 | Code Division Multiple Access technology compliant with Release 0 or later of the TIA-IS-95 standard |
| ISCR | Inter-System Cell Reselection |
| ISHO | Inter-System Handover |
| ISO | International Standards Organization |
| ISDN | Integrated Services Digital Network |
| ITU | International Telecommunication Union |
| Iub | Interface between RNC and Node B |
| K | Kelvin |
| k | Boltzmann constant ($1.38 \times 10^{-23}$ Joules/Kelvin) |
| kbps | Kilobits Per Second |
| kHz | kiloHertz |
| km/hr | Kilometers per Hour |
| KPI | Key Performance Indicator |
| L3 | Layer 3 |
| LA | Location Area |
| LAN | Local Area Network |
| LAU | Location Area Update |
| LNA | Low-Noise Amplifier |
| LNF | Lognormal Fading |
| LOS | Line of Sight |
| MAC | Medium Access Control |
| MAPL | Maximum Allowable Path Loss |
| Mbps | Megabits per second |
| MB | Megabyte |
| MCM | Measurement Control Message |
| Mcps | Megachips per second |
| mErl | milli-Erlangs |
| MHz | MegaHertz |
| MIB | Master Information Block |
| MM | Mobility Management |
| MMS | Multimedia Messaging Service |
| MO | Mobile Originated |
| MOS | Mean Opinion Score |
| MoU | Minutes of Use |
| MPEG | Moving Picture Experts Group |
| MRM | Measurement Report Message |
| ms | Millisecond |

| | |
|---|---|
| MS | Mobile Station |
| MSC | Mobile Switching Center |
| MT | Mobile Terminated |
| mW | milliWatts |
| NA | Not Applicable |
| NAK | Negative Acknowledgement |
| NAS | Non-Access Stratum |
| NBAP | Node B Application Part |
| NF | Noise Figure, or Noise Factor |
| NLOS | Non-Line of Sight |
| ns | Nanosecond |
| NSS | Network and Switching sub-System |
| O&M | Operation and Maintenance |
| OA&M | Operations, Administration, and Maintenance |
| OBS | Obstructed (opposite of Line of Sight) |
| OMC | Operation and Maintenance Center |
| OOS | Out of Service |
| OVSF | Orthogonal Variable Spreading Factor |
| PA | Power Amplifier |
| PAMS | Perceptual Analysis Measurement System |
| PAR | Peak to Average Ratio |
| PC | Personal Computer |
| PCCH | Paging Control Channel |
| PCCPCH | Primary Common Control Physical Channel |
| PCH | Paging Channel |
| P-CPICH | Primary Common Pilot Channel |
| PDA | Personal Digital Assistant |
| PCU | Packet Control Unit |
| PDC | Personal Digital Cellular |
| PDCP | Packet Data Convergence Protocol |
| PDSCH | Physical Downlink Shared Channel |
| PDP | Packet Data Protocol |
| PDU | Protocol Data Unit |
| PESQ | Perceptual Evaluation Speech Quality |
| PHY | Physical |
| PI | Page Indicator |
| PICH | Paging Indicator Channel |
| PLMN | Public Land Mobile Network |
| PO | Power Offset |
| PRACH | Physical Random Access Channel |
| PS | Packet Switched |
| PSC | Primary Scrambling Code |
| P-SCH | Primary Synchronization Channel |
| PSNR | Peak Signal-to-Noise Ratio |
| PSQM | Perceptual Speech Quality Measurement |
| PSTN | Public Switched Telephone Network |

| | |
|---|---|
| QAM | Quadrature Amplitude Modulation |
| QCIF | Quarter Common Intermediate Format |
| QoS | Quality of Service |
| QPSK | Quadrature Phase Shift Keying |
| RA | Routing Area |
| RAB | Radio Access Bearer |
| RACH | Random Access Channel |
| RANAP | Radio Access Network Application Part |
| RAU | Routing Area Update |
| RB | Radio Bearer |
| RF | Radio Frequency |
| RLA | Received Signal Level Averaged |
| RLC | Radio Link Control |
| RNC | Radio Network Controller |
| RNS | Radio Network Subsystems |
| ROT or RoT | Rise Over Thermal |
| RRC | Radio Resource Control |
| RSCP | Received Signal Code Power |
| RSSI | Received Signal Strength Indicator |
| RTT | Round Trip Time |
| RV | Redundancy Version |
| Rx | Receive |
| SCCPCH | Secondary Common Control Physical Channel |
| SCH | Synchronization Channel |
| sec | Second |
| SF | Spreading Factor |
| Sf_HORF | Softer Handover Reduction Factor |
| SGSN | Serving GPRS Support Node |
| SIB | System Information Block |
| SID | Silence Descriptor |
| SIM | Subscriber Identity Module |
| SINR | Signal-to-Interference-and-Noise Ratio |
| SIR | Signal-to-Interference Ratio |
| SM | Session Management |
| SNR | Signal-to-Noise Ratio |
| SPER | Sub-Packet Error Rate |
| SQCIF | Sub-Quarter Common Intermediate Format |
| SRB | Signal Radio Bearer |
| SRES | Signed Authentication Response |
| SSC | Secondary Scrambling Code |
| S-SCH | Secondary Synchronization Channel |
| T1 | Trunk Level 1, Digital transmission line, data rate of 1.544 Mbps |
| TB | Transport Block |
| TBS | Transport Block Size |
| TCP/IP | Transmission Control Protocol/Internet Protocol |
| TDD | Time Division Duplex |

| | |
|---|---|
| TDMA | Time Division Multiple Access |
| TFCI | Transport Format Combination Indicator |
| TFCS | Transport Format Combination Set |
| TFRC | Transport Format Resource Combination |
| TGCFN | Transmission Gap Connection Frame Number |
| TGD | Transmission Gap Distance |
| TGL | Transmission Gap Length |
| TGP | Transmission Gap Patterns |
| TGPL | Transmission Gap Pattern Length |
| TGPRC | Transmission Gap Pattern Repetition Count |
| TGPS | Transmission Gap Pattern Sequence |
| TGPSI | Transmission Gap Pattern Sequence Identifier |
| TGSN | Transmission Gap Slot Number |
| TM | Transparent Mode |
| TMA | Tower Mount Amplifier |
| TPC | Transmit Power Control |
| TRX | Transceiver |
| TSP | Transmit Status Prohibit |
| TSN | Transmission Sequence Number |
| TTI | Transmission Time Interval |
| TTT | Time-to-Trigger |
| TV | Television |
| Tx | Transmit |
| UARFCN | UTRA Absolute Radio Frequency Channel Number |
| UE | User Equipment |
| UL | Uplink |
| UM | Unacknowledged Mode |
| UMTS | Universal Mobile Telecommunications Systems |
| URA | UTRAN Registration Area |
| UTM | Universal Transverse Mercator |
| UTRA | Universal Terrestrial Radio Access |
| UTRAN | Universal Terrestrial Radio Access Network |
| UV | UltraViolet |
| VoIP | Voice over Internet Protocol |
| VLR | Visitor Location Register |
| VT | Video-Telephony |
| W | Watts |
| WAF | Wall Attenuation Factor |
| WCDMA | Wideband Code Division Multiple Access |
| WGS | World Geodetic System |
| WLAN | Wireless Local Area Network |
| WLL | Wireless Local Loop |
| YUV | Video format where luminance (Y) and chrominance (U and V) are a weighted function of R(ed) G(reen) B(lue) signal |

# 1

# Introduction to UMTS Networks

Patrick Chan, Andrea Garavaglia and Christophe Chevallier

Since their inception, mobile communications have become sophisticated and ubiquitous. However, as the popularity of mobile communications surged in the 1990s, Second Generation (2G) mobile cellular systems such as IS-95 and Global System for Mobile (GSM) were unable to meet the growing demand for more network capacity. At the same time, thanks to the Internet boom, users demanded better and faster data communications, which 2G technologies could not support.

Third Generation (3G) mobile systems have evolved and new services have been defined: mobile Internet browsing, e-mail, high-speed data transfer, video telephony, multimedia, video-on-demand, and audio-streaming. These data services had different Quality of Service (QoS) requirements and traffic characteristics in terms of burstiness and required bandwidth. More importantly, the projected traffic for these types of data services was expected to surpass voice traffic soon, marking a transition from the *voice paradigm* to the *data paradigm*. Existing cellular technology urgently needed a redesign to maximize the spectrum efficiency for the mixed traffic of both voice and data services. Another challenge was to provide global roaming and interoperability of different mobile communications across diverse mobile environments.

Toward these ends, the International Telecommunication Union (ITU), the European Telecommunications Standards Institute (ETSI), and other standardization organizations collaborated on the development of the Future Public Land Mobile Telecommunication Systems (FPLMTS). The project was later renamed International Mobile Telecommunications-2000 (IMT-2000). The goal of the project was to achieve convergence of the disparate competing technologies by encouraging collaborative work on one globally compatible system for wireless communications.

Set to operate at a 2 GHz carrier frequency band, the new 3G mobile cellular communication system needed to be backward-compatible with the 2G systems while improving system capacity and supporting both voice and data services. The system was expected

to support both circuit switched (CS) and packet switched (PS) data services. For the PS domain, the supported data rates were specified for the various mobile environments:

- Indoor or stationary – 2 Mbps
- Urban outdoor and pedestrian – 384 kbps
- Wide area vehicular – 144 kbps

Of the various original proposals, the two that gained significant traction were based on Code Division Multiple Access (CDMA): CDMA2000 1X and Universal Mobile Telecommunication System (UMTS).

- CDMA2000 1X was built as an extension to cdmaOne (IS-95), with enhancements to achieve high data speed and support various 3G services. CDMA2000 1X further evolved to support even higher data rates with a data optimized version: CDMA2000 1xEV-DO [1].
- UMTS was based on the existing GSM communication core network (CN) but opted for a totally new radio access technology in the form of a wideband version of CDMA (Wideband CDMA: WCDMA). The Wideband Code Division Multiple Access (WCDMA) proposal offered two different modes of operation: Frequency Division Duplex (FDD), where Uplink (UL) and Downlink (DL) traffic are carried by different radio channels; and Time Division Duplex (TDD), where the same radio channel is used for UL and DL traffic but at different times. Evolution to support higher data rates was achieved with the recent introduction of High-Speed Downlink Packet Access (HSDPA) [2].

The goal of this book is to address the deployment aspects of the FDD version of the UMTS IMT-2000 proposal – namely WCDMA network planning and optimization. While it is accepted that deploying a WCDMA network requires a thorough knowledge of the standard, this book leaves that to other existing works such as Refs [3] and [4], and concentrates instead on the key aspects necessary to successfully deploy and operate a WCDMA network in a real-world scenario. For newcomers to this technology, however, this chapter describes the basic network topology and underlying concepts associated with the technology.

## 1.1 UMTS Network Topology

When deploying a WCDMA network, most operators already have an existing 2G network. WCDMA was intended as a technology to evolve GSM network toward 3G services. Paralleling that evolution, this chapter first discusses GSM networks, then highlights the changes that are necessary to migrate to Release 99 of the WCDMA specification. The discussion then moves on to Release 5 of the specification and the network changes needed to support HSDPA.

### *1.1.1 GSM Network Architecture*

Figure 1.1 illustrates a GSM reference network [5], showing both the nodes and the interfaces to support operation in the CS and PS domains.