

Essentials of **LTE and LTE-A**

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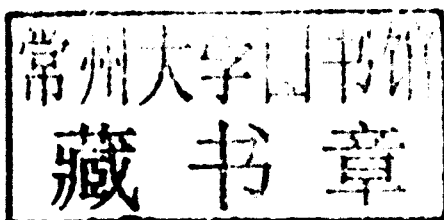


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Essentials of LTE and LTE-A

Amitabha Ghosh and Rapeepat Ratasuk

Motorola Solutions



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Essentials of LTE and LTE-A

This practical, one-stop guide will quickly bring you up-to-speed on LTE and LTE-Advanced (LTE-A). With everything you need to know about the theory and technology behind the standards, this is a must-have for engineers and managers in the wireless industry.

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- Covers the evolution of digital wireless technology, basics of LTE and LTE-A, design of downlink and uplink channels, multi-antenna techniques, and heterogeneous networks
- Analyzes performance benefits over competing technologies, including WiMAX and 802.16m
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- Includes numerous examples, including extensive system and link results
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To my parents for their continuous support and teaching me the value of education and thirst for knowledge; and to my family, Chittarupa, Devika, and Adit, for their support, encouragement, and love.

Amitabha Ghosh

To Tanita, Alisa, and Paul.

Rapeepat Ratasuk

Preface

The next-generation wireless broadband technology is changing the way we work, live, learn, and communicate through effective use of state-of-the-art mobile broadband technology. The packet-data-based revolution started around 2000 with the introduction of 1x Evolved Data Only (1xEV-DO) and 1x Evolved Data Voice (1xEV-DV) in 3GPP2 and High Speed Downlink Packet Access (HSDPA) in 3GPP. The wireless broadband fourth-generation technology (4G) is an evolution of the packet-based 3G system and provides a comprehensive evolution of the Universal Mobile Telecommunications System specifications so as to remain competitive with other broadband systems such as 802.16e (WiMAX). Specification work was started in late 2004 on Long Term Evolution (LTE) of the UMTS Terrestrial Radio Access and Radio Access Network intended for commercial deployment in 2010. Two main components constitute the LTE system architecture – the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC). The goals for the evolved system (E-UTRAN and EPC) included support for improved system capacity and coverage, high peak data rates, low latency, reduced operating costs, multi-antenna support, flexible bandwidth operations, and seamless integration with existing systems. The standardization work for LTE Rel-8 was completed in early 2009 and commercial LTE systems will be deployed in the 2011–2012 timeframe. LTE Rel-8 is currently evolving to LTE-Advanced (LTE Rel-9 and Rel-10), which will further improve the spectral efficiency, peak rates, and user experience compared with LTE Rel-8. LTE-Advanced has also been approved by the International Telecommunication Union (ITU) as an International Mobile Telecommunications-Advanced (IMT-A) technology.

The book is organized in seven chapters. Chapter 1 gives a timeline and brief description of the evolution of digital wireless technology starting with GSM, IS-95, cdma2000 1x, WCDMA Rel-99, HSPA (Rel-5/6),

WiMAX, LTE, LTE-Advanced, and 802.16m with emphasis on how supported data rates, throughput, and applications have evolved. Chapter 2 provides a brief description of LTE requirements and system architecture together with the basic principles of orthogonal frequency-division multiple-access (OFDMA) and single-carrier frequency-division multiple-access (SC-FDMA) technology. Chapter 3 dives into the basic details of LTE downlink OFDMA transmission including transport and physical-channel structure, control-channel details, system operations, and inter-cell interference coordination schemes both for FDD (Frequency-Division Duplex) and for TDD (Time-Division Duplex) LTE. Aspects of downlink system performance under various channels and antenna structure are summarized at the end of the chapter.

Chapter 4 provides the details of LTE uplink transport and physical-channel structure, control-channel details, random access, system operations, and fractional power control followed by uplink system performance under various channels and antenna configurations. The LTE system offers a rich suite of multiple-antenna techniques that can be used in various scenarios to improve the performance and user experience. Chapter 5 describes various multi-antenna schemes for LTE downlink and uplink and provides a system-performance comparison of various multi-antenna schemes. Chapter 6 is devoted to technologies for LTE-Advanced (LTE-A). The chapter describes the requirements for IMT-A and how LTE-A will satisfy those requirements using enhanced technologies. The technologies include support of wider bandwidth using carrier aggregation, uplink spatial multiplexing, enhanced downlink spatial multiplexing, coordinated multiple-point transmission and reception, and heterogeneous networks including relays, distributed antenna systems, and pico-cells. Aspects of the system performance of these enhancements are presented and compared with the performance of the legacy LTE system.

Finally, Chapter 7 provides a comparison of LTE/LTE-A with other competitive broadband systems such as 802.16e/802.16m. As the name signifies, this chapter outlines both qualitative and quantitative differences between the 802.16e/802.16m (WiMAX) system and the LTE/LTE-A system. System performance comparisons between these systems are presented for various reuse schemes and antenna configurations.

At the time of writing, there are ongoing discussions within the operator and vendor community regarding further evolution of LTE-A technology. These enhancements will appear in Rel-11 and Rel-12 of 3GPP and will offer better user experience, lower cost per bit, greener base stations, and efficient self-organizing networks.

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Several of our colleagues made a significant impact on the materials presented in this book. We would like to acknowledge and thank Prakash Moorut for his comments and suggestions on the spectrum-engineering aspects, Bishwarup Mondal, who provided critical comments, simulations, and suggestions for improving the contents related to multi-antenna systems and heterogeneous networks, Nitin Mangalvedhe for providing us with some of the simulation results and his in-depth comments relating to heterogeneous networks, Joe Hoffman for providing help related to the economic aspect of wireless broadband systems, Mark Cudak for providing us with his expertise on WiMAX-related issues, and Tim Thomas, who reviewed the entire first draft of the book and provided constructive comments and criticisms. Throughout our professional careers at Motorola we had the good fortune of working and learning from some of the most talented people in the cellular industry, including Ken Stewart, Bob Love, the late Dennis Schaeffer, Fan Wang, Joe Pedziwiatr, Paul Steinberg, Phil Fleming, Fred Vook, Weimin Xiao, Brian Classon, and 3GPP colleagues, among many others. Finally, we would like to thank our superiors Sudhakar Ramakrishna and Bill Payne for providing us with encouragement and support for undertaking this project.

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1 Genesis of wireless broadband technology (from 2G to 4.5G)

1.1 Genesis of wireless technology

The digital cellular technology revolution started with the introduction of GSM (Groupe Special Mobile) in the late 1980s. The GSM technology was based on time-division multiple access (TDMA) and was capable of supporting data services of up to 9.6 kbps. In the early 1990s, IS-95, a standard based on code-division multiple-access (CDMA) technology was introduced. This offered data rates of up to 14.4 kbps and improved spectral efficiencies over a GSM system. Subsequently, both these technologies evolved over time, with each phase offering higher peak rates and improved sector/edge spectral efficiencies. Both GSM and IS-95 CDMA evolved in different phases. In 1997, the Generalized Packet Radio System (GPRS) based on packet data instead of circuit data was standardized, followed by Enhanced Data Rates for Global Evolution (EDGE). Also, at the end of 1998, the Third-Generation Partnership Project (3GPP) was started. This was responsible for defining a third-generation (3G) wideband CDMA (WCDMA) standard based on the evolved GSM core network. At the same time the GSM standardization work was moved from ETSI SMG2 to 3GPP, and was called GERAN. Similarly, in the United States the IS-95 standard evolved to cdma2000 under the umbrella of Third-Generation Partnership Project 2 (3GPP2).

The packet-data-based revolution started around 2000 with the introduction of cdma2000 1x Evolved Data Only (1xEV-DO) and 1x Evolved Data Voice (1xEV-DV) in 3GPP2 and High Speed Downlink Packet Access (HSDPA) in 3GPP. These 3.5G technologies had the following common attributes: adaptive modulation and coding, hybrid automatic repeat request, fast scheduling based on smaller frame size, turbo codes, and de-centralized architecture to reduce latency. In the next phase of development of 3.5G technology, improved uplink functionality was added to 3GPP and 1xEV-DO systems. Concurrently, advances were made in cdma2000 1x

technology (i.e. cdma 1x-advanced), which included an advanced vocoder, mobile receive diversity, an advanced receiver with interference cancellation, and advanced power control. It may be noted that, although 1xEV-DV was standardized, it never took off as a technology due to the reluctance of the operator community to adopt the technology and the absence of proper eco-systems.

A disruptive technology known as mobile WiMAX based on orthogonal frequency-division multiplexing (OFDM) technology was standardized in 2006, and was dubbed the first 4G multiple access system. This technology was based on the IEEE 802.16e standard and offered scalable bandwidth up to 20 MHz, higher peak rates, and better spectral efficiencies than those provided by 3.5G systems. With the emergence of packet-based wireless broadband systems such as WiMAX, it was evident that a comprehensive evolution of UMTS would be required in order for it to remain competitive in the long term. As a result, work began on Evolved UMTS Terrestrial Radio Access (E-UTRA) based on the OFDM air interface. The Long Term Evolution (LTE Rel-8) system supports high peak data rates and provides low latency, improved system capacity and coverage, reduced operating costs, efficient multi-antenna support, efficient support for packet data transmission, flexible bandwidth of up to 20 MHz, and seamless integration with existing systems. The CDMA-based HSPA technology is also being enhanced to support quad carriers (bandwidth up to 20 MHz), MIMO, and higher-order modulation both on the downlink and on the uplink. A 4G proposal called Ultra Mobile Broadband (UMB) based on OFDM was also adopted by 3GPP2, but it failed to make any impact.

Both WiMAX and LTE are currently being enhanced (LTE-Advanced and 802.16m) so as to support even higher peak rates, higher throughput and coverage, and lower latencies resulting in a better user experience. Further, LTE-Advanced and 802.16m also enable one to meet or exceed IMT-Advanced requirements. Finally, the 4.5G wireless broadband systems will be standardized in 3GPP Rel-12 in the 2013–2017 timeframe. It is clear that 4.5G systems will further enhance the 4G systems in terms of user experience, sector spectral efficiency, and peak rates, but the exact features for 4.5G systems are still being decided.

The Digital Video Broadcasting (DVB) standards, which include Mediaflow and Multimedia Broadcast Multicast Service (MBMS) designed for LTE and HSPA, for global delivery of broadcast services such as digital television are also evolving to provide better spectral efficiencies for broadcast services.

The wireless evolution chart of 2G to 4.5G technology migration is shown in Figure 1.1.

The downlink peak rate improvement on going from 2G to 4.5G technology is shown in Table 1.1.

The improvement in downlink sector spectral efficiencies on going from 2G to 4.5G systems is shown in Figure 1.2.

It may be observed from Figure 1.2 that there has been an improvement by a factor of 30 in sector spectral efficiency with 4G systems compared with 2G, which results in improved cost per bit. Figure 1.3 shows an example of how mobile broadband cost per bit decreases exponentially with technology innovation in wireless technology.

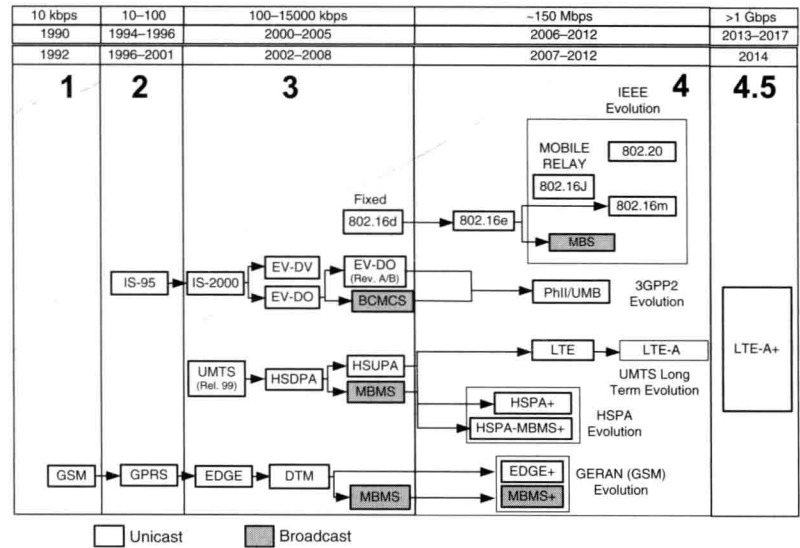


Figure 1.1. Standards evolution of wireless technologies (from 2G to 4.5G).