



EVOLVED PACKET SYSTEM (EPS)

The LTE and SAE Evolution of 3G UMTS

Pierre Lescuyer | Thierry Lucidarme

 WILEY

EVOLVED PACKET SYSTEM (EPS)

THE LTE AND SAE EVOLUTION OF 3G UMTS

Pierre Lescuyer and Thierry Lucidarme

*Both of
Alcatel-Lucent, France*



John Wiley & Sons, Ltd

EVOLVED PACKET SYSTEM (EPS)

EVOLVED PACKET SYSTEM (EPS)

THE LTE AND SAE EVOLUTION OF 3G UMTS

Pierre Lescuyer and Thierry Lucidarme

*Both of
Alcatel-Lucent, France*



John Wiley & Sons, Ltd

Copyright © 2008

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
Visit our Home Page on www.wiley.com

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except under the terms of the Copyright, Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd, 90 Tottenham Court Road, London W1T 4LP, UK, without the permission in writing of the Publisher. Requests to the Publisher should be addressed to the Permissions Department, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England, or emailed to permreq@wiley.co.uk, or faxed to (+44) 1243 770620.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The Publisher is not associated with any product or vendor mentioned in this book.

All trademarks referred to in the text of this publication are the property of their respective owners.

This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the Publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Other Wiley Editorial Offices

John Wiley & Sons Inc., 111 River Street, Hoboken, NJ 07030, USA

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

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Library of Congress Cataloging-in-Publication Data

Lescuyer, Pierre, 1967-

Evolved packet system (EPS): the LTE and SAE evolution of 3G UMTS / Pierre Lescuyer and Thierry Lucidarme.
p. cm.

Includes index.

ISBN 978-0-470-05976-0 (cloth)

1. Universal Mobile Telecommunications System. 2. Wireless communication systems. I. Lucidarme, Thierry. II. Title. III.

Title: Evolved packet system, the long term evolution and system architecture evolution of 3G Universal Mobile Telecommunications System.

TK5103.L47 2008

621.384-dc22

2007033388

British Library Cataloguing in Publication Data

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

ISBN 978-0-470-05976-0 (HB)

Typeset by 10/12pt Times by Thomson Digital Noida, 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

Preface	xi
1 Introduction	1
1.1 Wireless World Picture	1
1.2 About Technologies	3
1.2.1 <i>Heterogeneous 2G Systems</i>	4
1.2.2 <i>'MAP' and 'IS-41' Systems</i>	4
1.2.3 <i>The MAP Technologies</i>	6
1.2.4 <i>The IS-41 Technologies</i>	9
1.3 Standards and Organizations	12
1.3.1 <i>The Role of ITU</i>	12
1.3.2 <i>3G Cross-Country Standardization Bodies</i>	13
1.3.3 <i>The Structure of 3GPP</i>	14
1.3.4 <i>The NGN Evolution</i>	17
1.3.5 <i>The NGMN Initiative</i>	18
1.4 Spectrum	20
1.5 The Evolution of UMTS	21
1.5.1 <i>1st Evolution Driver: The Move towards Data Applications</i>	21
1.5.2 <i>2nd Evolution Driver: Enhanced Radio Interface Capabilities</i>	23
1.5.3 <i>What Will Change Within the Network?</i>	23
1.5.4 <i>What is Described in this Book?</i>	24
1.6 Links and Documents	24
1.6.1 <i>Useful Web Sites</i>	24
1.6.2 <i>Evolved UMTS Specifications</i>	24
2 Evolved UMTS Overview	27
2.1 The Access Network Requirements	27
2.1.1 <i>Radio Interface Throughput</i>	28
2.1.2 <i>Data Transmission Latency</i>	28
2.1.3 <i>Terminal State Transition</i>	29
2.1.4 <i>Mobility</i>	30
2.1.5 <i>Spectrum Flexibility</i>	30
2.1.6 <i>Co-existence and Inter-Working with Existing UMTS</i>	31

2.2	Evolved UMTS Concepts	31
2.2.1	<i>A Packet-Only Architecture</i>	32
2.2.2	<i>A Shared Radio Interface</i>	35
2.2.3	<i>Other Access Technologies</i>	35
2.3	Overall Evolved UMTS Architecture	36
2.3.1	<i>E-UTRAN: The Evolved Access Network</i>	37
2.3.2	<i>EPC: The Evolved Packet Core Network</i>	39
2.3.3	<i>The HSS</i>	47
2.4	The IMS Subsystem	50
2.4.1	<i>The Session Control Function</i>	50
2.4.2	<i>The Media Gateway Nodes</i>	52
2.5	Policy Control and Charging	53
2.5.1	<i>Policy Control in UMTS</i>	53
2.5.2	<i>Evolved UMTS Policy Control</i>	57
2.5.3	<i>The Charging Architecture</i>	57
2.6	The Terminal	61
2.6.1	<i>The User Device Architecture</i>	61
2.6.2	<i>Terminal Capabilities</i>	63
2.6.3	<i>The Subscriber Module</i>	63
2.7	The Evolved UMTS Interfaces	68
2.8	Major Disruptions with 3G UTRAN-FDD Networks	68
2.8.1	<i>About Soft Handover</i>	68
2.8.2	<i>About Compressed Mode</i>	71
2.8.3	<i>About Dedicated Channels</i>	72
3	Physical Layer of E-UTRAN	75
3.1	Basic Concepts of Evolved 3G Radio Interface	75
3.2	OFDM (Orthogonal Frequency Division Multiplex)	76
3.2.1	<i>OFDMA Multiple Access</i>	80
3.2.2	<i>MC-CDMA Multiple Access</i>	82
3.2.3	<i>Common Points between OFDM, CDMA, MC-CDMA, etc.</i>	82
3.2.4	<i>Frequency Stability Considerations for OFDM Systems</i>	84
3.2.5	<i>System Load in OFDMA Systems</i>	84
3.2.6	<i>SC-FDMA: The PAPR (Peak-Average-Power-Ratio) Problem</i>	85
3.2.7	<i>Dimensioning an OFDM System</i>	89
3.3	MIMO (Multiple Input Multiple Output)	91
3.3.1	<i>Traditional Beamforming</i>	91
3.3.2	<i>MIMO Channel and Capacity</i>	92
3.3.3	<i>A Simplified View of MIMO 2.2</i>	96
3.3.4	<i>The Harmonious Coupling between OFDM and MIMO</i>	97
3.3.5	<i>MIMO: A Classification Attempt</i>	98
3.3.6	<i>Some Classical Open Loop MIMO Schemes</i>	99
3.3.7	<i>Notions of Cyclic Delay Diversity (CDD)</i>	102
3.3.8	<i>MIMO Schemes and Link Adaptation</i>	103
3.3.9	<i>Improving MIMO with Some Feedback</i>	104

3.3.10	<i>MU-MIMO, Virtual MIMO and Transmit Diversity</i>	107
3.3.11	<i>Towards a Generalized Downlink Scheme</i>	108
3.4	Architecture of the Base Station	109
3.4.1	<i>The Block Scheme of the Base Station</i>	109
3.4.2	<i>The Analogue-to-Digital Conversion</i>	111
3.4.3	<i>Power Amplification (PA) Basics</i>	113
3.4.4	<i>Cellular Antennas Basics</i>	114
3.5	The E-UTRAN Physical Layer Standard	118
3.6	FDD and TDD Arrangement for E-UTRAN	118
3.6.1	<i>A Word about Interferences in TDD Mode</i>	119
3.6.2	<i>Some Basic Physical Parameters</i>	120
3.6.3	<i>TDD and Existing UTRAN Compatibility</i>	121
3.6.4	<i>Combined FDD-TDD Mode</i>	122
3.7	Downlink Scheme: OFDMA (FDD/TDD)	122
3.7.1	<i>Downlink Physical Channels and Signals</i>	124
3.7.2	<i>Physical Signal Transmitter Architecture</i>	125
3.7.3	<i>Downlink Data Multiplexing</i>	126
3.7.4	<i>Scrambling</i>	130
3.7.5	<i>Modulation Scheme</i>	130
3.7.6	<i>Downlink Scheduling Information and Uplink Grant</i>	132
3.7.7	<i>Channel Coding</i>	132
3.7.8	<i>OFDM Signal Generation</i>	132
3.7.9	<i>Downlink MIMO</i>	133
3.7.10	<i>Channels Layer Mapping, Precoding and Mapping to Resource Elements</i>	137
3.7.11	<i>E-MBMS Concepts</i>	140
3.7.12	<i>Downlink Link Adaptation</i>	143
3.7.13	<i>HARQ</i>	143
3.7.14	<i>Downlink Packet Scheduling</i>	146
3.7.15	<i>Cell Search and Acquisition</i>	148
3.7.16	<i>Methods of Limiting the Inter-Cell Interference</i>	153
3.7.17	<i>Downlink Physical Layer Measurements</i>	155
3.8	Uplink Scheme: SC-FDMA (FDD/TDD)	156
3.8.1	<i>Uplink Physical Channel and Signals</i>	156
3.8.2	<i>SC-FDMA</i>	156
3.8.3	<i>Uplink Subframe Structure</i>	157
3.8.4	<i>Resource Grid</i>	159
3.8.5	<i>PUSCH Physical Characteristics</i>	160
3.8.6	<i>PUCCH Physical Characteristics</i>	161
3.8.7	<i>Uplink Multiplexing Including Reference Signals</i>	162
3.8.8	<i>Reference Signals</i>	162
3.8.9	<i>Multiplexing of L1/L2 Control Signalling</i>	163
3.8.10	<i>Channel Coding and Physical Channel Mapping</i>	164
3.8.11	<i>SC-FDMA Signal Generation</i>	164
3.8.12	<i>The Random Access Channel</i>	164
3.8.13	<i>Uplink-Downlink Frame Timing</i>	168

3.8.14	<i>Scheduling</i>	168
3.8.15	<i>Link Adaptation</i>	168
3.8.16	<i>Uplink HARQ</i>	169
4	Evolved UMTS Architecture	171
4.1	Overall Architecture	171
4.1.1	<i>Evolved UMTS Node Features</i>	172
4.1.2	<i>E-UTRAN Network Interfaces</i>	176
4.1.3	<i>S1 Interface</i>	177
4.1.4	<i>S1 Flexibility</i>	181
4.1.5	<i>X2 Interface</i>	183
4.2	User and Control Planes	184
4.2.1	<i>User Plane Architecture</i>	184
4.2.2	<i>Control Plane Architecture</i>	188
4.3	Radio Interface Protocols	189
4.3.1	<i>The E-UTRAN Radio Layered Architecture</i>	189
4.3.2	<i>The Radio Channels</i>	190
4.3.3	<i>PHY</i>	194
4.3.4	<i>MAC</i>	196
4.3.5	<i>RLC</i>	197
4.3.6	<i>RRC</i>	198
4.3.7	<i>PDCP</i>	200
4.3.8	<i>NAS Protocols</i>	206
4.4	IMS Protocols	209
4.4.1	<i>The IMS Protocol Stack</i>	210
4.4.2	<i>SIP</i>	210
4.4.3	<i>SDP</i>	220
4.4.4	<i>RTP</i>	223
4.4.5	<i>A SIP/SDP IMS Example</i>	227
5	Life in EPS Networks	229
5.1	Network Attachment	229
5.1.1	<i>Broadcast of System Information</i>	230
5.1.2	<i>Cell Selection</i>	231
5.1.3	<i>The Initial Access</i>	232
5.1.4	<i>Registration</i>	236
5.1.5	<i>De-registration</i>	240
5.2	Communication Sessions	241
5.2.1	<i>Terminal States</i>	241
5.2.2	<i>Quality of Service in Evolved UMTS</i>	245
5.2.3	<i>Security Overview</i>	249
5.2.4	<i>User Security in EPS</i>	253
5.2.5	<i>User Security in IMS</i>	260
5.2.6	<i>Session Setup</i>	261
5.2.7	<i>Data Transmission</i>	265

5.3	Mobility in IDLE Mode	266
5.3.1	<i>Cell Reselection Principles</i>	266
5.3.2	<i>Terminal Location Management</i>	266
5.3.3	<i>Tracking Area Update</i>	269
5.4	Mobility in ACTIVE Mode	270
5.4.1	<i>Intra-E-UTRAN Mobility with X2 Support</i>	272
5.4.2	<i>Intra-E-UTRAN Mobility without X2 Support</i>	274
5.4.3	<i>Intra-E-UTRAN Mobility with EPC Node Relocation</i>	276
5.4.4	<i>Mobility between 2G/3G Packet and E-UTRAN</i>	278
6	The Services	281
6.1	The Role of OMA	281
6.2	Push-to-talk Over Cellular	282
6.2.1	<i>Service Architecture</i>	284
6.2.2	<i>PoC Protocol Suite</i>	287
6.2.3	<i>An Example of PoC Session Setup</i>	289
6.2.4	<i>Charging Aspects</i>	292
6.3	Presence	294
6.3.1	<i>Service Architecture</i>	294
6.3.2	<i>An Example of a Presence Session</i>	295
6.3.3	<i>Charging Aspects</i>	297
6.4	Broadcast and Multicast	298
6.4.1	<i>Some Definitions</i>	298
6.4.2	<i>Typical Applications</i>	299
6.4.3	<i>Service Architecture</i>	299
6.4.4	<i>MBMS Security</i>	303
6.4.5	<i>The MBMS Service Steps</i>	305
6.4.6	<i>The E-UTRAN Aspects of MBMS</i>	307
6.4.7	<i>Charging Aspects</i>	307
6.5	Voice and Multimedia Telephony	309
6.5.1	<i>About Circuit and Packet Voice Support</i>	309
6.5.2	<i>Service Architecture</i>	312
6.5.3	<i>About Information Coding</i>	313
6.5.4	<i>About Supplementary Services</i>	317
6.5.5	<i>Multimedia Services in EPS Systems</i>	320
	Glossary	323
	Index	335

Preface

With more than two billion customers, there is no doubt that 2G GSM and 3G UMTS cellular technologies are a worldwide success, adopted by most countries and network operators. The 3G UMTS technology has significantly evolved since the first declination. The first release of the standard, published in 1999, was mostly oriented towards dedicated channel allocation, and circuit-switched service support. Later on, the standard evolved to high-speed packet radio interface for downlink transmission (HSDPA for High Speed Downlink Packet Access) and uplink transmission HSUPA as a clear orientation towards IMS (IP Multimedia Subsystem) and IP-based services.

EPS (Evolved Packet System) represents the very latest evolution of the UMTS standard. EPS is also known by other acronyms related to technical study items being worked on at 3GPP standard committees: **LTE** (Long Term Evolution), which is dedicated to the evolution of the radio interface, and **SAE** (System Architecture Evolution), which focuses on Core Network architecture evolution.

Although still a 3G-related standard, EPS proposes a significant improvement step, with a brand new radio interface and an evolved architecture for both the Access and the Core Network parts. The two major disruptions brought by EPS are:

- **Improved performances** – characterized by a spectrum efficiency which is twice as large as HSDPA/HSUPA.
- **A packet-only system** – resulting in a unified and simplified architecture.

EPS is specified as part of the 3GPP family and, from that perspective, EPS will benefit from the same ecosystem that made the success of GSM and UMTS technologies. In addition, it is believed that technical and architectural evolutions brought by EPS prefigure future 4G networks (also known as IMT-Advanced networks).

This book presents the EPS evolution, as introduced in Release 8 of the 3GPP standard. It is not a substitute to the 3GPP standard, and advanced readers willing to dig into any specific domain of EPS are encouraged to consult the 3GPP specification documents which are referenced, when appropriate, through the different chapters.

The objective here is rather to provide a comprehensive system end-to-end vision of EPS, from the radio interface to the service level, including network architecture, radio protocols, as well as subscriber and session management. As EPS was not thought of as a completely new and standalone technology, the authors have also tried to show the inheritance and relations with 2G GSM and early 3G UMTS in terms of ground principles and technical aspects.

The technical content of this book is based on early documents and standards available at the time of writing. For that reason, the view presented here might be slightly different from the actual reference standard. This should, however, be constrained to very limited parts or specific details of this book.

1

Introduction

This chapter is an introduction to the evolution of UMTS systems, also known as EPS (Evolved Packet System). It provides a picture of current wireless and cellular communications, as an introduction to the requirements and motivations for Evolved 3G systems, which are the subject of the next chapter.

This chapter presents the following elements:

- A brief history of digital cellular systems, from 2G to the latest 3G evolutions.
- The evolution of the subscriber base.
- The various organizations which are supporting 3G and Evolved 3G system specifications.
- An overview of the spectrum usage.
- A list of Web links and documents directly connected to Evolved UMTS.

1.1 Wireless World Picture

Wireless cellular communication is certainly one of the major evolutions provided to the telecommunication world, experiencing an exponential growth from the early 1990s.

Wireless communication systems started to emerge in the mid-1980s, first based on so-called 1G (first-generation) analogue technologies like AMPS (Advanced Mobile Phone System) in the United States or NMT (Nordic Mobile Telephone) in Northern Europe. Those systems have evolved to 2G (second-generation) digital radio – providing robustness and better spectral efficiency – and, ultimately, to 3G, so as to offer global mobility and improved end-user experience over a wide range of services.

The unprecedented success of wireless communication has multiple business repercussions, by developing the potential for voice traffic and added-value services like Instant text and Voice Messaging, Multimedia Messaging (MMS), high-value content delivery or streaming, location-based services, etc.

As of mid-2006, there were:

- 2.3 billion mobile subscribers worldwide.
- 1.8 billion GSM mobile subscribers – GSM represented a 78% market share of cellular subscribers.