Chapter 1

LTE Introduction

1.1 Introduction

The challenge for any book tackling a subject as broad and deep as a completely new cellular radio standard is one of focus. The process of just creating the Long Term Evolution (LTE) specifications alone has taken several years and involved tens of thousands of temporary documents, thousands of hours of meetings, and hundreds of engineers. The result is several thousand pages of specifications. Now the hard work is underway, turning those specifications into real products that deliver real services to real people willing to pay real money. A single book of this length must therefore choose its subject wisely if it is to do more than just scratch the surface of such a complex problem.

The focus that Agilent has chosen for this book is a practical one: to explain design and measurement tools and techniques that engineering teams can use to accelerate turning the LTE specifications into a working system. The first half of the book provides an overview of the specifications starting in Chapter 2 with RF aspects and moving through the physical layer and upper layer signaling to the System Architecture Evolution (SAE) in Chapter 5. Due to limited space, the material in Chapters 2 through 5 should be viewed as an introduction to the technology rather than a deep exposition. For many, this level of detail will be sufficient but anyone tasked with designing or testing parts of the system will always need to refer directly to the specifications. The emphasis in the opening chapters is often on visual rather than mathematical explanations of the concepts. The latter can always be found in the specifications and should be considered sufficient information to build the system. However, the former approach of providing an alternative, more accessible explanation is often helpful prior to gaining a more detailed understanding directly from the specifications.

Having set the context for LTE in the opening chapters, the bulk of the remainder of the book provides a more detailed study of the extensive range of design and measurement techniques and tools that are available to help bring LTE from theory to deployment.

1.2 LTE System Overview

Before describing the LTE system it is useful to explain some of the terminology surrounding LTE since the history and naming of the technology is not intuitive. Some guidance can be found in the Vocabulary of 3GPP Specifications 21.905 [1], although this document is not comprehensive. The term LTE is actually a project name of the Third Generation Partnership Project (3GPP). The goal of the project, which started in November 2004, was to determine the long-term evolution of 3GPP's universal

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mobile telephone system (UMTS). UMTS was also a 3GPP project that studied several candidate technologies before choosing wideband code division multiple access (W-CDMA) for the radio access network (RAN). The terms UMTS and W-CDMA are now interchangeable, although that was not the case before the technology was selected.

In a similar way, the project name LTE is now inextricably linked with the underlying technology, which is described as an evolution of UMTS although LTE and UMTS actually have very little in common. The UMTS RAN has two major components: (1) the universal terrestrial radio access (UTRA), which is the air interface including the user equipment (UE) or mobile phone, and (2) the universal terrestrial radio access network (UTRAN), which includes the radio network controller (RNC) and the base station, which is also known as the node B (NB).

Because LTE is the evolution of UMTS, LTE's equivalent components are thus named evolved UTRA (E-UTRA) and evolved UTRAN (E-UTRAN). These are the formal terms used to describe the RAN. The system, however, is more than just the RAN since there is also the parallel 3GPP project called System Architecture Evolution that is defining a new all internet protocol (IP) packet-only core network known as the evolved packet core (EPC). The combination of the EPC and the evolved RAN (E-UTRA plus E-UTRAN) is the evolved packet system (EPS). Depending on the context, any of the terms LTE, E-UTRA, E-UTRAN, SAE, EPC, and EPS may get used to describe some or all of the system. Although EPS is the only correct term for the overall system, the name of the system will often be written as LTE/SAE or even simply LTE, as in the title of this book.

Figure 1.2-1 shows a high level view of how the evolved RAN and EPC interact with legacy radio access technologies.

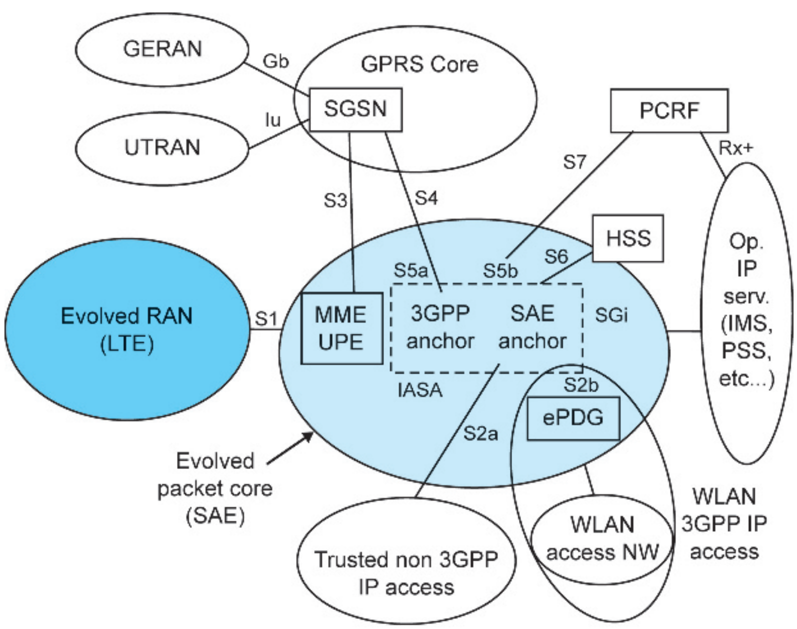

Figure 1.2-1. Logical high-level architecture for the evolved system (from 23.882 [2] Figure 4.2-1)

The 3GPP drive to simplify the existing hybrid circuit-switched/packet-switched core network is behind the SAE project to define an all-IP core network. This new architecture is a flatter, packet-only core network that is an essential part of delivering the higher throughput, lower cost, and lower latency that is the goal of the LTE evolved RAN. The EPC is also designed to provide seamless interworking with existing 3GPP and non-3GPP radio access technologies. The overall requirements for the System Architecture Evolution are summarized in 22.278 [3]. A more detailed description of the EPC is given in Chapter 5.

1.3 The Evolution from UMTS to LTE

The LTE specifications are written by 3GPP, which is a partnership of standards development organizations (SDOs). The work of 3GPP is public and, as will be described in Section 1.6, it is possible to gain access to all meeting reports, working documents, and published specifications from the 3GPP website: www.3gpp.org. The organizational partners that make up 3GPP are the Japanese Association of Radio Industries and Businesses (ARIB), the USA Alliance for Telecommunications Industry Solutions (ATIS), the China Communications Standards Association (CCSA), the European Telecommunications Standards Institute (ETSI), the Korean Telecommunications Technology Association (TTA), and the Japanese Telecommunications Technology Committee (TTC).

Table 1.3-1. Evolution of the UMTS specifications

Release	Functional freeze	Main UMTS feature of release
Rel-99	March 2000	Basic 3.84 Mcps W-CDMA (FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	Dec 2007	HSPA+ (64QAM downlink, MIMO, 16QAM uplink) LTE and SAE feasibility study
Rel-8	Dec 2008	LTE work item—OFDMA/SC-FDMA air interface, SAE work item—new IP core network, Dual-carrier HSDPA
Rel-9	December 2009	Home BS, MBMS, multi-standard radio, dual-carrier HSUPA, dual-carrier HSDPA with MIMO, dual-cell HSDPA
Rel-10	March 2011 (protocols 3 months later)	LTE-Advanced (carrier aggregation, 8x DL MIMO, 4x UL MIMO, relaying, enhanced inter-cell interference coordination (eICIC)), 4-carrier HSDPA
Rel-11	September 2012 (protocols 3 months later)	Further eICIC, coordinated multi-point transmission (CoMP), carrier aggregation scenarios, 8-carrier HSDPA
Rel-12	TBD—2014? (Stage 1 March 2013)	Further interference coordination, inter-site carrier aggregation, others TBD including dynamic TDD and LTE-D

Table 1.3-1 summarizes the evolution of the 3GPP UMTS specifications towards LTE. Each release of the 3GPP specifications represents a defined set of features. A summary of the contents of any release can be found at www.3gpp.org/releases.

The date given for the functional freeze relates to the date when no further new items can be added to the release. After this point any further changes to the specifications are restricted to essential corrections. The commercial launch date of a release depends on the period of time following the functional freeze before the specifications are considered stable and then implemented into commercial systems. For the first release of UMTS the delay between functional freeze and commercial launch was several years, although the delay for subsequent releases was progressively shorter. The delay between functional freeze and the first commercial launch for LTE/SAE was remarkably short, being less than a year, although it was two years before significant numbers of networks started operation. This period included the time taken to develop and implement the conformance test cases, which required significant work that could not begin until the feature set of the release was frozen and UEs had been implemented.

After Release 99, 3GPP stopped naming releases with the year and opted for a new scheme starting with Release 4. This choice was driven by the document version numbering scheme explained in Section 1.6. Release 4 introduced the 1.28 Mcps narrow band version of W-CDMA, also known as time division synchronous code division multiple access (TD-SCDMA). Following this was Release 5, in which high speed downlink packet access (HSDPA) introduced packet-based data services to UMTS in the same way that the general packet radio service (GPRS) did for GSM in Release 97 (1998). The completion of packet data for UMTS was achieved in Release 6 with the addition of high speed uplink packet access (HSUPA), although the official term for this technology is enhanced dedicated channel (E-DCH). HSDPA and HSUPA are now known collectively as high speed packet access (HSPA). Release 7 contained the first work on LTE/SAE with the completion of feasibility studies, and further improvements were made to HSPA such as downlink multiple input-multiple output (MIMO), 64QAM on the downlink, and 16QAM on the uplink. In Release 8, HSPA continued to evolve with the addition of numerous smaller features such as dual-carrier HSDPA and 64QAM with MIMO. Dual-carrier HSUPA was introduced in Release 9, four-carrier HSDPA in Release 10, and eight-carrier HSDPA in Release 11.

The main work in Release 8 was the specification of LTE and SAE, which is the main focus of this book. Work beyond Release 8 up to Release 12 is summarized in Chapter 8, although there are many references to features from these later releases throughout this second edition. Within 3GPP there are additional standardization activities not shown in Table 1.3-1 such as those for the GSM enhanced RAN (GERAN) and the IP multimedia subsystem (IMS).

1.4 LTE/SAE Requirements

The high level requirements for LTE/SAE include reduced cost per bit, better service provisioning, flexible use of new and existing frequency bands, simplified network architecture with open interfaces, and an allowance for reasonable power consumption by terminals. These are detailed in the LTE feasibility study 25.912 [4] and in the LTE requirements document 25.913 [5]. To meet the requirements for LTE outlined in 25.913 [5], LTE/SAE has been specified to achieve the following:

- Increased downlink and uplink peak data rates, as shown in Table 1.4-1. Note that the downlink is specified for single input single output (SISO) and MIMO antenna configurations at a fixed 64QAM modulation depth, whereas the uplink is specified only for SISO but at different modulation depths. These figures represent the physical limitation of the FDD air interface in ideal radio conditions with allowance for signaling overheads. Lower peak rates are specified for specific UE categories, and performance requirements under non-ideal radio conditions have also been developed. Comparable figures exist in [4] for TDD operation.

- Scalable channel bandwidths of 1.4 MHz, 3.0 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz in both the uplink and the downlink.
- Spectral efficiency improvements over Release 6 HSPA of 3 to 4 times in the downlink and 2 to 3 times in the uplink.
- Sub-5 ms latency for small IP packets.
- Performance optimized for low mobile speeds from 0 to 15 km/h supported with high performance from 15 to 120 km/h; functional support from 120 to 350 km/h. Support for 350 to 500 km/h is under consideration.
- Co-existence with legacy standards while evolving toward an all-IP network.

Table 1.4-1. LTE (FDD) downlink and uplink peak data rates (from 25.912 [4] Tables 13.1 & 13.1a)

FDD downlink peak data rates (64QAM)			
Antenna configuration	SISO	2x2 MIMO	4x4 MIMO
Peak data rate (Mbps)	100	172.8	326.4
FDD uplink peak data rates (single antenna)			
Modulation depth	QPSK	16QAM	64QAM
Peak data rate (Mbps)	50	57.6	86.4

The headline data rates in Table 1.4-1 represent the corner case of what can be achieved with the LTE RAN in perfect radio conditions; however, it is necessary for practical reasons to introduce lower levels of performance to enable a range of implementation choices for system deployment. This is achieved through the introduction of UE categories as specified in 36.306 [6] and shown in Table 1.4-2. These are similar in concept to the categories used to specify different levels of performance for HSPA.

Table 1.4-2. Peak data rates for UE categories (derived from 36.306 [6] Tables 4.1-1 and 4.1-2)

UE category	Peak downlink data rate (Mbps)	Number of downlink spatial layers	Peak uplink data rate (Mbps)	Number of uplink spatial layers	Support for 64QAM in uplink
Category 1	10.296	1	5.16	1	No
Category 2	51.024	2	25.456	1	No
Category 3	102.048	2	51.024	1	No
Category 4	150.752	2	51.024	1	No
Category 5	302.752	4	75.376	1	Yes
Category 6	301.504	2 or 4	51.024	1, 2, or 4	No
Category 7	301.504	2 or 4	10.2048	1, 2, or 4	No
Category 8	2998.56	8	149.776	8	Yes

Categories 6, 7, and 8 were added in Release 10 for the support of LTE-Advanced (see Section 8.3). There are other attributes associated with UE categories, but the peak data rates, downlink antenna configuration, and uplink 64QAM support are the categories most commonly referenced.

The emphasis so far has been on the peak data rates but what really matters for the performance of a new system is the improvement that can be achieved in average and cell-edge data rates. The reference configuration against which LTE/SAE performance targets have been set is defined in 25.913 [5] as being Release 6 UMTS. For the downlink the reference is HSDPA Type 1 (receive diversity but no equalizer or interference cancellation). For the uplink the reference configuration is single transmitter with diversity reception at the Node B. Table 1.4-3 shows the simulated downlink performance of UMTS versus the design targets for LTE. This is taken from the work of 3GPP during the LTE feasibility study [7]. Table 1.4-4 shows a similar set of results for the uplink taken from [8].

Table 1.4-3. Comparison of UMTS Release 6 and LTE downlink performance requirements

Case 1 500m inter-site distance	Spectrum efficiency		Mean user throughput		Cell-edge user throughput	
	(bps/Hz/cell)	x UTRA	[bps/Hz/user]	x UTRA	(bps/Hz/user)	x UTRA
UTRA baseline 1x2	0.53	x1.0	0.05	x1.0	0.02	x1.0
E-UTRA 2x2 SU-MIMO	1.69	x3.2	0.17	x3.2	0.05	x2.7
E-UTRA 4x2 SU-MIMO	1.87	x3.5	0.19	x3.5	0.06	x3.0
E-UTRA 4x4 SU-MIMO	2.67	x5.0	0.27	x5.0	0.08	x4.4

Table 1.4-4. Comparison of UMTS Release 6 and LTE uplink performance requirements

Case 1 500m inter-site distance	Spectrum efficiency		Mean user throughput		Cell-edge user throughput	
	(bps/Hz/cell)	x UTRA	(bps/Hz/user)	x UTRA	[bps/Hz/user]	x UTRA
UTRA baseline	0.332	x1.0	0.033	x1.0	0.009	x1.0
E-UTRA 1x2	0.735	x2.2	0.073	x2.2	0.024	x2.5
E-UTRA 1x2 MU-MIMO	0.675	x2.0	0.067	x2.0	0.023	x2.4
E-UTRA 1x4	1.103	x3.3	0.110	x3.3	0.052	x5.5
E-UTRA 2x2 SU-MIMO	0.776	x2.3	0.078	x2.3	0.010	x1.1

From these tables the LTE design targets of 2x to 4x improvement over UMTS Release 6 can be seen. Note, however, that UMTS did not stand still and there were Release 7 and Release 8 UMTS enhancements that significantly narrow the gap between UMTS and LTE. The evolution of UMTS continues through Release 12. Although the figures in Tables 1.4-3 and 1.4-4 are meaningful and user-centric, they were derived from system-level simulations and are not typical of the methods used to specify minimum performance. The simulations involved calculation of throughput by repeatedly dropping ten users randomly into the cell. From this data a distribution of performance was developed and the mean user throughput calculated. The cell-edge throughput was defined as the 5th percentile of the throughput cumulative distribution. For this reason the cell-edge figures are quoted per user assuming 10 users per cell, whereas the mean user throughput is independent of the number of users.

When it comes to defining minimum performance requirements for individual UE, the simulation methods used to derive the figures in Tables 1.4-3 and 1.4-4 cannot be used. Instead, the minimum requirements for UMTS and LTE involve spot measurement of throughput at specific high and low interference conditions, and for additional simplicity, this is done without the use of closed-loop adaptive modulation and coding. This approach to defining performance is pragmatic but it means that there is no direct correlation between the results from the conformance tests and the simulated system performance in Tables 1.4-3 and 1.4-4.

1.5 LTE/SAE Timeline

The timeline of LTE/SAE development is shown in Figure 1.5-1. This includes the work of 3GPP in drafting the specifications as well as the conformance test activities of the Global Certification Forum (GCF) and the trials carried out by the LTE/SAE Trial Initiative (LSTI). The work of GCF towards the certification of UE against the 3GPP conformance specifications is covered in some detail in Section 7.4. The LSTI, whose work was completed in 2011, was an industry forum and complimentary group that worked in parallel with 3GPP and GCF with the intent of accelerating the acceptance and deployment of LTE/SAE as the logical choice of the industry for next-generation networks. The work of LSTI was split into four phases. The first phase was proof of concept of the basic principles of LTE/SAE, using early prototypes not necessarily compliant with the specifications. The second phase was interoperability development testing (IODT), which was a more detailed phase of testing using standards-compliant equipment but not necessarily commercial platforms. The third stage was interoperability testing (IOT), similar in scope to IODT but using platforms intended for commercial deployment. The final phase was Friendly Customer Trials, which ran through 2010. GCF certified the first UE against the 3GPP conformance tests in April 2011. By November 2012 there were 102 FDD and 11 TDD commercial networks launched in 51 countries according to the Global Suppliers Association.

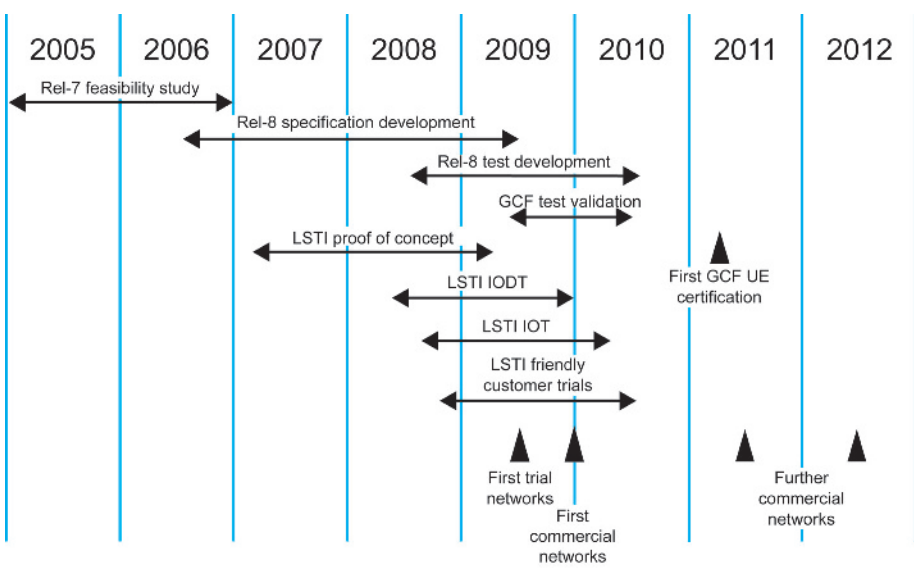

Figure 1.5-1. Projected LTE/SAE timeline

1.6 Introduction to the 3GPP LTE/SAE Specification Documents

The final section in this introductory chapter provides a summary of the LTE/SAE specification documents and where to find them.

1.6.1 Finding 3GPP Documents

A good place to start looking for documents is www.3gpp.org/specifications. From there it is possible to access the specification documents in a number of different ways, including by release number, publication date, or specification number. A comprehensive list of all 3GPP specifications giving the latest versions for all releases can be found at www.3gpp.org/ftp/Specs/html-info/SpecReleaseMatrix.htm. Each document has a version number from which the status of the document can be determined. For instance with 36.101 Vx.y.z, x represents the stability of the document, y the major update, and z an editorial update. If x is 1, then the document is an early draft for information only. If x is 2, then the document has been presented for approval. If x is greater than 2, then the document has been approved and is under change control. Once under change control, the value of x also indicates the release. Therefore a 3 is Release 1999, a 4 is Release 4, a 5 is Release 5, and so on. Most documents in an active release will get updated quarterly, which is indicated by an increment of the y digit. The document will also contain the date when it was approved by the technical specification group (TSG) responsible for drafting it. This date is often one month earlier than the official quarterly publication date.

To avoid confusion, individual documents should be referenced only by the version number. Groups of documents can be usefully referenced by the publication date—e.g., 2008–12—but note that the version numbers of the latest documents for that date will vary depending on how frequently each document has been updated. For example, at 2008–12, most of the physical layer specifications were at version 8.5.0 but most of the radio specifications were at version 8.4.0. It is therefore meaningless to refer to "version 8.x.y" of the specifications unless only one particular document is being referenced.

The set of specifications valid on any publication date will contain the latest version of every document regardless of whether the document was actually updated since the previous publication date. To access the specifications by publication date, go to ftp://ftp.3gpp.org/specs/. Within each date there will be a list of all the Releases and from there each series of specifications can be accessed. If only the latest documents for a Release are required, go to ftp://ftp.3gpp.org/specs/latest/. Newer, less stable, unpublished documents can often be found at ftp://ftp.3gpp.org/specs/Latest-drafts/, although care must be taken when making use of this type of information.

All versions of the releases of any particular document number can be accessed from ftp://ftp.3gpp.org/specs/archive/. This information can also be obtained from ftp://ftp.3gpp.org/Specs/html-info/, which provides the most comprehensive information. From this link the easiest way to proceed is to select a series of documents; e.g., ftp://ftp.3gpp.org/Specs/html-info/36-series.htm. This location will list all 36-series documents with the document numbers and titles. Selecting a document number will access a page with the full history of the document for all releases, including a named rapporteur and the working group (WG) responsible for drafting the document. At the bottom of the page will be a link to the change request (CR) history, which brings up yet another page listing all the changes made to the document and linked back to the TSG that approved the changes.

By tracing back through the CR history for a document it is possible to access the minutes and temporary documents of the TSG in which the change was finally approved. For instance, tracing back through a CR to 36.101 V8.5.0 (2008-12) would lead to a temporary document of the TSG RAN meeting that approved it stored under ftp://ftp.3gpp.org/tsg_ran/TSG_RAN/TSGR_42/. The change history of a document can also be found in the final annex of the document, but linking to the CR documents themselves has to be done via the website. The lowest level of detail is found by accessing the WG documents from a specific TSG meeting. An example for TSG RAN WG4, who develop the LTE 36.100-series radio specifications, can be found at ftp://ftp.3gpp.org/tsg_ran/WG4_Radio/TSGR4_50/. The link to this WG from the document can also be made from the html-info link given above.

The final way to gain insight into the work of the standards development process is to read the email exploders of the various committees. This capability is hosted by ETSI at http://list.etsi.org/.

1.6.2 LTE/SAE Document Structure

The feasibility study for LTE/SAE took place in Release 7, resulting in several Technical Reports of which [1] and [2] are the most significant.

The LTE RAN specifications are contained in the 36-series of Release 8 and are divided into the following categories:

- 36.100 series, covering radio specifications and eNB conformance testing
- 36.200 series, covering layer 1 (physical layer) specifications
- 36.300 series, covering layer 2 and 3 (air interface signalling) specifications
- 36.400 series, covering network signaling specifications
- 36.500 series, covering user equipment conformance testing
- 36.800 and 36.900 series, which are technical reports containing background information.

The latest versions of the 36 series documents can be found at www.3gpp.org/ftp/Specs/latest/Rel-11/36_series/.

The SAE specifications for the EPC are more scattered than those for the RAN and are found in the 22-series, 23-series, 24-series, 29-series, and 33-series of Release 8, with work happening in parallel in Release 9. A more comprehensive list of relevant EPC documents can be found in Chapter 5.

1.7 References

[1] 3GPP TR 21.905 V11.2.0 (2012-09) Vocabulary for 3GPP Specifications

[2] 3GPP TR 23.882 V8.0.0 (2008-09) 3GPP System Architecture Evolution: Report on Technical Options and Conclusions

[3] 3GPP TS 22.278 V12.1.0 (2012-06) Service requirements for the Evolved Packet System (EPS)

[4] 3GPP TR 25.912 V11.0.0 (2012-09) Feasibility study for evolved Universal Terrestrial Radio Access (UTRA) and evolved Universal Terrestrial Radio Access Network (UTRAN)

[5] 3GPP TR 25.913 V9.0.0 (2009-12) Requirements for Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN)

[6] 3GPP TR 36.306 V11.1.0 (2012-09) Evolved Universal terrestrial Radio Access Network (E-UTRA); User Equipment (UE) radio access capabilities

[7] 3GPP TSG RAN WG1 Tdoc R1-072578 "Summary of downlink performance evaluation," Ericsson, May 2007

[8] 3GPP TSG RAN WG1 Tdoc R1-072261 "LTE performance evaluation — uplink summary," Nokia, May 2007

Links to all reference documents can be found at www.agilent.com/find/ltebook.