Long Term Evolution (LTE) | LTE-Advanced | LTE-Advanced Pro

LONG TERM EVOLUTION (LTE)

LTE Logo **Rel-8/Rel-9**

UTRA (Universal Terrestrial Radio Access) as a 3rd generation system, with the enhancements provided by High Speed Packet Access (HSPA), for both downlink and uplink, will remain highly competitive for several years. Nevertheless, the industry that has developed the 3GPP technologies, launched a project in Dec. 2004 called Long Term Evolution (LTE) to study requirements for a new air interface called Evolved UTRA (E-UTRA).

Note: The terms LTE and E-UTRA are synonymous, however the radio specifications talk rather about E-UTRA.

The results of this study i.e. the E-UTRA/LTE requirements were documented in Rel-7 3GPP TR 25.913:

- Significantly increased peak data rates e.g. 100 Mbps in downlink/50 Mbps in uplink
- Increased bitrates at the edge of cells assuming current site locations
- Improved spectrum efficiency e.g. 2-4 x Rel-6
- Reduced latency
- Scaleable bandwidth for a greater flexibility in frequency allocations
- Reduced capital and operational expenditure including backhaul
- Acceptable system and terminal complexity, cost and power consumption
- Support for inter-working with existing 3G systems and non-3GPP specified systems
- Efficient support of the various types of services, especially from the PS domain (e.g. Voice over IP, Presence)
- Optimized for low mobile speed but supporting high mobile speed (up to 500 km/h).

Following the definition of the E-UTRA/LTE requirements, the same Rel-7 study produced a 3GPP TR 25.912 "**Feasibility study for evolved Universal Terrestrial Radio Access (UTRA) and Universal Terrestrial Radio Access Network (UTRAN)**" to describe how the radio part of the system could be designed. Corresponding normative E-UTRA/LTE work followed then from Sep. 2006 until March 2009 in Rel-8 specifications.

In parallel to the radio architecture evolution a Study on 3GPP System Architecture Evolution (SAE) was carried out with the objective to develop a framework for an evolution or migration of the 3GPP system to a higher-data-rate, lower-latency, packet-optimized system that supports multiple Radio Access Technologies. The focus of this work was on the PS domain with the assumption that voice services are supported in this domain.
This study resulted in Rel-8 3GPP TR 23.882 and was followed by corresponding normative Rel-8 work.

LTE Standardisation history

Although the term "Evolved UTRA" implies a gradual enhancement of the existing 3rd generation UMTS system, it became finally a different radio access technology:

- while UMTS started with a focus on circuit-switched data that was then more and more enhanced via shared channels and HSPA into the direction of a packet switched system, LTE is a pure packet-switched system
- while UMTS was using CDMA, LTE is using OFDMA (Orthogonal Frequency Division Multiple Access) in downlink (evolved NodeB (eNodeB) => User Equipment (UE)) and SC-FDMA (Single Carrier- Frequency Division Multiple Access) in uplink (UE => eNodeB)
  Note 1: SC-FDMA has lower peak-to-average power ratios (PAPR) than OFDMA which was preferred for an easier UE power amplifier design/a higher efficiency (increased coverage/lower power consumption)
  Note 2: SC-FDMA is also called DFT-S-OFDM which indicates that it can be understood as a precoding (by Discrete Fourier transform) plus the same OFDMA that is used in downlink
- while UMTS (at least FDD and 3,84Mcps TDD) used a channel bandwidth of 5MHz, LTE allows 6 different channel bandwidths: 1,4/3/5/10/15/20MHz
- while UMTS has an RNC (radio network controler) between NodeB and core network, the functionalities of this network entity are split between eNodeB and core network in LTE => no RNC in LTE => flat/simpler radio architecture

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Nevertheless, UMTS/UTRA as well as LTE/E-UTRA use both a 10ms radio frame, both have FDD and TDD modes and LTE/E-UTRA supports full interoperability with UMTS/UTRA and GSM/GERAN/EDGE.

LTE-ADVANCED



Rel-10/Rel-11/Rel-12

Additional spectrum proposed for IMT systems by WRC-07 in 2007 (in 450 MHz band, in UHF band (698-960 MHz), in 2.3-2.4 GHz band, in C-band(3400-4200 MHz)) as well as the ITU-R request for the development of an IMT-Advanced radio interface (Circular Letter of March 2008) triggered developments of the 4th generation of mobile communication systems.

According to ITU-R M.1645 (overall objectives for beyond IMT-2000) and M.2134 (IMT-Advanced requirements) the key features for IMT-Advanced were summarized as follows:

- a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner
- compatibility of services within IMT and with fixed networks
- capability of interworking with other radio access systems
- high-quality mobile services
- user equipment suitable for worldwide use
- user-friendly applications, services and equipment
- worldwide roaming capability
- enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research)

3GPP was at that time in the phase to complete its Rel-8 LTE WI and it started an early Rel-9 study item (FS_RAN_LTEA, RP-091360) in March 2008 to define in 3GPP TR 36.913 the requirements for a mobile communication system called LTE-Advanced under the following conditions:

- LTE-Advanced shall be an evolution of Release 8 LTE system
- All requirements of LTE of 3GPP TR 25.913 are also valid for LTE-Advanced
- LTE-Advanced shall meet or exceed IMT-Advanced requirements within the ITU-R time plan

Note: The terms LTE-Advanced and Advanced E-UTRA are synonymous.

3GPP TR 36.913 on "**Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced)**" was approved at RAN #40 in June 2008 (still under Rel-8).

The following figure from ITU-R M.1645 illustrates the differences between IMT-2000 (3rd generation) and IMT-Advanced (4th generation):



In addition, the same study started in March 2008 a 3GPP TR 36.912 on Feasibility study for "Further Advancements for E-UTRA (LTE-Advanced)" in order to analyse certain areas in which LTE could be enhanced, e.g.

- Support of wider bandwidth: aggregation of multiple component carriers with up to 20MHz bandwidth,
- Spatial multiplexing: DL up to 8 layers, UL up to 4 layers,
- Coordinated multiple point transmission and reception: to improve the coverage of high data rates, the cell-edge throughput and/or to increase system throughput
- Relaying functionality: to improve e.g. the coverage of high data rates, group mobility, temporary network deployment, the cell-edge throughput and/or to provide coverage in new areas

to fulfill and exceed the IMT-Advanced requirements.

This TR 36.912 was approved in Sep.2009 (RAN #45) as Rel-9 TR and further updated at RAN #46 and RAN #47 (March 2010) where the SI was completed.

In Release 10 individual work items were started introducing enhancements of LTE that were discussed in the Rel-9 study item for LTE-Advanced:

- Carrier Aggregation for LTE (LTE_CA): Dec.09 - June 11; RP-100661
- UL multiple antenna transmission for LTE (LTE_UL_MIMO): Dec.09 - June 11; RP-100959
- Enhanced Downlink Multiple Antenna Transmission for LTE (LTE_eDL_MIMO): Dec.09 - March 11; RP-100196

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- Coordinated Multi-Point Operation for LTE: only a study was started in Rel-10 which completed in Rel-11 and resulted in normative work in Rel-11 with further enhancements in Rel-13 and Rel-15
- Relays for LTE (LTE_Relay): Dec.09 - June 11; RP-110911
- Latency reduction: WI was stopped as it was not possible to complete this in Rel-10 (it came back a L2 latency reduction in Rel-14 and was completed there)
- Further enhancements to MBMS for LTE (MBMS_LTE_enh): June 10 - March 11; RP-101244
- LTE Self Optimizing Networks (SON) enhancements (SONenh_LTE): March 10 - June 11; RP-101004
- Minimization of drive tests for E-UTRAN and UTRAN (MDT_UMTSLTE): Dec.09 - June 11; RP-100360

Note: There is no separate Radio Access Technology "LTE-Advanced". All enhancements of LTE in Rel-10 and beyond are integrated into the LTE specifications as they were developed in Rel-8 and Rel-9.

3GPP contributed to IMT-Advanced project of ITU-R via an early preliminary input from RAN #41 in Sep.2008 (RP-080763) and a final submission including self-evaluation results from RAN #45 in Sep.2009 (RP-090939).

Note: RP-090939 includes RP-090745 which provides the characteristics of LTE-Advanced in a condensed template format.

In Jan. 2012, the Radiocommunication Assembly approved ITU-R Recommendation M.2012 "Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)" (RP-120005) and confirmed LTE-Advanced as IMT-Advanced radio interface technology.

Note 1: There is only one other IMT-Advanced radio interface technology called "WirelessMAN-Advanced" developed by IEEE).

Note 2: About every 2 years, ITU-R M.2012 is updated by 3GPP with latest enhancements.

LTE-ADVANCED PRO

Rel-13 and above

All enhancements of LTE of Rel-13 and beyond (if not related to 5G) are running under the trademark "LTE Advanced Pro", for example:

Rel-13 (Sep.14-Dec.15, ASN.1 freeze: March 16):

- Narrowband Internet of Things (IOT)
- Further LTE Physical Layer Enhancements for MTC
- Dual Connectivity enhancements for LTE
  Extension of Dual Connectivity in E-UTRAN
- Licensed-Assisted Access (LAA) using LTE
- Elevation Beamforming/Full-Dimension (FD) MIMO for LTE
- Indoor Positioning enhancements for UTRA and LTE
- Further Enhancements of Minimization of Drive Tests for E-UTRAN
- Enhanced LTE Device to Device Proximity Services
- Multicarrier Load Distribution of UEs in LTE
- Support of single-cell point-to-multipoint transmission in LTE
- Enhanced Signalling for Inter-eNB Coordinated Multi-Point (CoMP) for LTE
- RAN enhancements for extended DRX in LTE
- LTE-WLAN Radio Level Integration and Interworking Enhancement,
  LTE-WLAN RAN Level Integration supporting legacy WLAN
- RAN aspects of Application specific Congestion control for Data Communication
- Base Station (BS) RF requirements for Active Antenna System (AAS),
  SON for AAS-based deployments
- Dedicated Core Networks
- RAN Aspects of RAN Sharing Enhancements for LTE

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- Radiated requirements for the verification of multi-antenna reception perf. of UEs
- UE core requirements for uplink 64 QAM
- LTE DL 4 Rx antenna ports

Rel-14 (Dec.15-March 17, ASN.1 freeze: June 17):

- Enhancements of NB-IoT
- Further enhanced MTC for LTE
- Flexible eNB-ID and Cell-ID in E-UTRAN
- Enhanced LAA for LTE
- Support for V2V services based on LTE sidelink, LTE-based V2X Services
- Enhancements on Full-Dimension (FD) MIMO for LTE
- Downlink Multiuser Superposition Transmission for LTE
- SRS (sounding reference signal) switching between LTE component carriers
- Further Indoor Positioning Enhancements for UTRA and LTE
- Uplink Capacity Enhancements for LTE
- eMBMS enhancements for LTE
- L2 latency reduction techniques for LTE
- Further mobility enhancements in LTE
- Voice and Video Enhancement for LTE
- Enhanced LTE-WLAN Aggregation (LWA), Enhanced LTE WLAN Radio Level Integration with IPsec Tunnel (eLWIP)
- Enhancements of Dedicated Core (DECOR) Networks for UMTS and LTE
- LTE Measurement Gap Enhancement
- Requirements for a new UE category with single receiver based on Cat.1 for LTE
- Performance enhancements for high speed scenario in LTE
- 4 receiver (RX) antenna ports with Carrier Aggregation for LTE downlink (DL)
- Multi-Band Base Station testing with three or more bands
- Radiated perf. requirements for the verification of multi-antenna reception of UEs

Note: For Rel-15 and onwards, LTE related specifications even carry the 5G logo as they were part of the SRIT IMT-2020 input (see 5G page for further explanation).

Rel-15 (March 17-June 18, ASN.1 freeze: Sep.18):

- Further NB-IoT enhancements
- Even further enhanced MTC for LTE
- Enhancements to LTE operation in unlicensed spectrum
- V2X phase 2 based on LTE
- Further enhancements to Coordinated Multi-Point (CoMP) Operation for LTE
- UE Positioning Accuracy Enhancements for LTE
- Enhancements for high capacity stationary wireless link and intro of DL 1024 QAM
- Bluetooth/WLAN measurement collection in LTE Minimization of Drive Tests
- Quality of Experience Measurement Collection for streaming services in E-UTRAN
- UL data compression in LTE
- Increased number of E-UTRAN data bearers
- Further video enhancements for LTE
- Shortened TTI and processing time for LTE, Ultra Reliable Low Latency Communication for LTE
- LTE connectivity to 5G-CN
- Enhanced LTE Support for Aerial Vehicles
- Enhancing LTE CA Utilization
- UE requirements for network-based CRS interference mitigation for LTE
- UE requirements for LTE DL 8Rx antenna ports
- Enhancements of BS RF and EMC requirements for Active Antenna System

Rel-16 (June 18 - June 20, ASN.1 freeze: June 20):

- Additional enhancements for NB-IoT
- Additional MTC enhancements for LTE
- DL MIMO efficiency enhancements for LTE
- Even further mobility enhancement in E-UTRAN
- Support for NavIC Navigation Satellite System for LTE
- Further performance enhancement for LTE in high speed scenario
- LTE-based 5G terrestrial broadcast

And a number of work items driven by LTE & NR:

- 5G V2X with NR sidelink
- Multi-RAT Dual-Connectivity and Carrier Aggregation enhancements (LTE, NR)
- Optimisations on UE radio capability signalling – NR/E-UTRA Aspects
- eNB(s) Architecture Evolution for E-UTRAN and NG-RAN

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- Introduction of capability set(s) to multi-standard radio specifications

Rel-17 (June 20 - March 22, ASN.1 freeze planned for June 22):

- Additional enhancements for NB-IoT and LTE-MTC
- NB-IoT/eMTC support for Non-Terrestrial Networks
- Additional LTE bands for UE categories M1/M2/NB1/NB2
- Further LTE Carrier Aggregation combinations
- New bands and bandwidth allocation for 5G terrestrial broadcast

And a number of work items driven by LTE & NR:

- Further Multi-RAT Dual-Connectivity enhancements
- Support for Multi-SIM devices for LTE/NR
- Enhanced eNB(s) architecture evolution for E-UTRAN and NG-RAN
- Enhancement of data collection for SON (Self-Organising Networks)/MDT (Minimization of Drive Tests) in NR standalone and MR-DC (Multi-Radio Dual Connectivity)
- Further RRM enhancement for NR and Multi-RAT-Dual Connectivity
- NR and Multi-RAT-Dual Connectivity measurement gap enhancements
- User Plane Integrity Protection support for EPC connected architectures
- High power UE (power class 2) for EN-DC
- Band combinations for concurrent operation of NR/LTE Uu bands/band combinations and one NR/LTE V2X PC5 band
- LTE/NR spectrum sharing in LTE band 40/NR band n40
- Simultaneous Rx/Tx band combinations for NR Carrier Aggregation/Dual Connectivity, NR Supplemental Uplink and LTE/NR Dual Connectivity
- Further band combinations for Dual Connectivity LTE/NR

Rel-18 (March 22 - December 23, ASN.1 freeze planned for March 24):

- IoT (Internet of Things) NTN (non-terrestrial network) enhancements
- Introduction of LTE TDD band in 1 670 to 1 675 MHz

And a number of work items driven by LTE & NR:

- In-Device Co-existence (IDC) enhancements for NR and MR-DC
- Artificial Intelligence (AI)/Machine Learning (ML) for NG-RAN
- Further enhancement of data collection for SON (Self-Organizing Networks)/MDT (Minimization of Drive Tests) in NR standalone and MR-DC (Multi-Radio Dual Connectivity)
- BS/UE EMC enhancements for NR and LTE
- Further RF requirements enhancement for NR and EN-DC in frequency range 1 (FR1)
- Support of intra-band non-collocated EN-DC/NR-CA deployment
- Further enhancements on NR and MR-DC measurement gaps and measurements without gaps

LTE specifications can be found under: 3GPP TS 36.-series specifications (if only LTE is affected) or 3GPP TS 37.-series specifications (if also other radio access technologies like UMTS or GERAN or NR are covered in this specification), e.g. stage 2 in 3GPP TS 36.300.

3GPP TS 21.201 provides a list of all specifications related to the 4th generation (including core network EPC (Evolved Packet Core) and system aspects). The 4G network architecture is described in 3GPP TS 23.003

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