LTE in a Nutshell:

System Overview

WHITE PAPER

Introduction: Setting The Context

Long Term Evolution (LTE) is the latest mobile telecommunication system defined by the 3rd Generation Partnership Project (3GPP). It follows up on the GSM/GPRS/EDGE family of systems which are collectively categorized as 'Second Generation' and on 'Third Generation' systems family of standards that include UMTS/HSPA. These standards have different air interface and core network architecture. For instance, GSM has a TDMA air interface whereas UMTS is based on WCDMA and LTE is based on OFDMA. GSM features a circuit switched core network, LTE is based on a flat IP-architecture, and UMTS has a hybrid circuit switched core for voice traffic and packet-switched core for data traffic. The evolution of these standards reflects the transition of the mobile cellular network from a voice-centric application to data-centric applications of which voice is one application. Figure 1 shows the 3GPP technology standards development track.

LTE refers to the evolution of the radio network. The evolution of the non-radio aspects of the complete system is done under the term 'System Architecture Evolution' or SAE which includes the Evolved Packet Core (EPC). SAE offers an optimized (flat) IP-based architecture. LTE and SAE together comprise the Evolved Packet System (EPS).

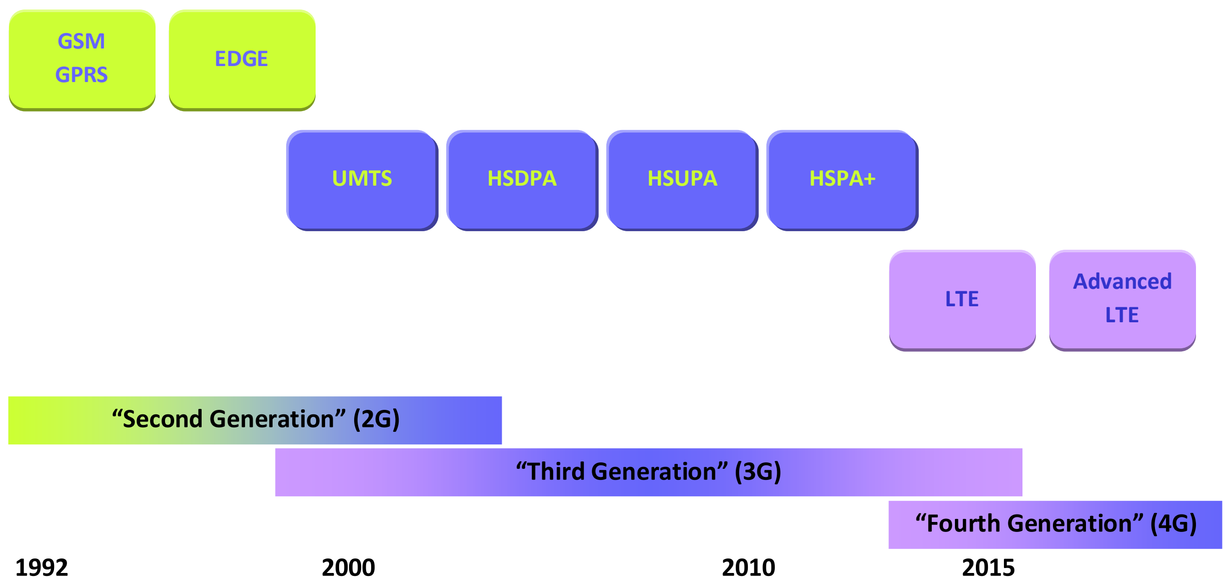


FIGURE 1 3GPP STANDARDS EVOLUTION.

Requirements and Targets for LTE

The key system performance requirements for LTE were finalized in 2005 and can be summarized as follows:

1- Increased user data rate and cell-edge bit rate for uniformity of service provision;

2- Reduced delays in transmission latency and connection establishment time;

3- Reduced cost per bit by providing improved spectral efficiency;

4- Greater flexibility in spectrum usage;

5- Simplified network architecture;

6- Seamless mobility, including between different access technologies;

7- Reasonable power consumption for the mobile terminal.

The main performance metrics are summarized in Table 1 which shows a comparison with UMTS Release 6 (HSDPA/HSUPA)—the most advanced version available at the time LTE requirements were defined[1].

Table 1 Summary of key system performance requirement targets for LTE.

	Parameter	Absolute Requirement	Reference Base Line (R6: HSDPA/HSUPA)	Comment
Downlink	Peak transmission rate	> 100 Mbps	7 x 14.4 Mbps	LTE: 20 MHz FDD, 2x2 spatial multiplexing Reference: HSDPA in 5 MHz FDD, single antenna
	Peak spectral efficiency	> 5 bps/Hz	3 bps/Hz	
	Average cell spectral efficiency	> 1.6 - 2.1 bps/Hz/cell	3 - 4 x 0.53 bps/Hz/cell	LTE: 2x2 spatial multiplexing, interference rejection combining receiver. Reference: HSDPA, Rake receiver, 2 receive antennas
	Cell edge spectral efficiency	> 0.04 - 0.06 bps/Hz/user	2 - 3 x 0.02 bps/Hz	As above, 10 users assumed per cell
	Broadcast spectral efficiency	> 1 bps/Hz	N/A	Dedicated carriers for broadcast mode
Uplink	Peak transmission rate	> 50 Mbps	5 x 11 Mbps	LTE: 20 MHz FDD, 2x2 spatial multiplexing Reference: HSUPA in 5 MHz FDD, single antenna
	Peak spectral efficiency	> 2.55 bps/Hz	2 bps/Hz	
	Average cell spectral efficiency	> 0.66 - 1.0 bps/Hz/cell	2 - 3 x 0.33 bps/Hz	LTE: single antenna transmission, IRC receiver. Reference: HSUPA, Rake receiver, 2 receive antennas
	Cell edge spectral efficiency	> 0.02 - 0.03 bps/Hz/user	2 - 3 x 0.01 bps/Hz	As above, 10 users assumed per cell
System	User plane latency	< 10 ms	1/5	Two way radio delay
	Connection setup latency	< 100 ms		Excludes paging delay and Non-Access Stratum (NAS) signalling delay
	Operating bandwidth	1.4 - 20 MHz	5 MHz	
	VoIP capacity	> 60 sessions/MHz/cell (per NGMN)		

The peak rate is one of the most important parameters since it's often quoted in marketing literature and talked about within the industry circles where it's often misdefined. The peak rate is the maximum throughput per user

[1] LTE is defined in Release 8.0. Release 7.0 defines HSPA+ which is an enhancement to HSPA. HSPA combines HSDPA and HSUPA defined in Releases 5 and 6, respectively.

assuming the whole bandwidth is allocated to a single user with the highest modulation and coding scheme and the maximum number of antennas supported (20 MHz channel; 2 transmit / 2 receive antennas on the base station antennas and 1 transmit / 2 receive antennas on the mobile terminal in case of LTE). In actual usage scenario, it is very rare if not impossible to achieve the claimed peak rate because multiple users share a cell with varying distance from the base station and with less than ideal propagation conditions for radio signals.

In addition to the above requirements, LTE is designed to support mobility services for terminals moving at speeds up to 350 km/h to accommodate high speed trains. Handover between cells must be possible without interruptions—i.e. with imperceptible delay and packet loss for voice calls.

In addition to system performance requirements, there are interoperability and architectural requirements that LTE needs to comply with. Some of these requirements are as follows:

1- Operation in wide range of frequency bands and spectral allocation sizes. In this case, LTE supports both FDD and TDD access modes. Current mobile telecommunications systems are based on FDD and this will be the mainstream deployment scenario for LTE. TDD radio access networks have seen wider deployment in recent years in broadband fixed wireless access applications.

2- Inter-working with other radio access technologies, in particular with earlier 3GPP technologies (GSM, UMTS), and other non 3GPP technologies like WiFi (IEEE 802.11).

3- Flat architecture consisting of one type of node: eNodeB (representing the base station).

4- Open interfaces and support for multi-vendor equipment interoperability.

5- Efficient mechanisms for operation and maintenance including self-optimization functions.

6- Support for easy deployment and configuration (for example, Femto base stations).

NETWORK ARCHITECTURE

The Evolved Packet System, which comprises LTE and SAE, aims to provide seamless IP connectivity for a user with the Packet Data Network (PDN) for accessing the Internet and running VoIP service. Figure 2 shows the network elements that comprise the EPS.

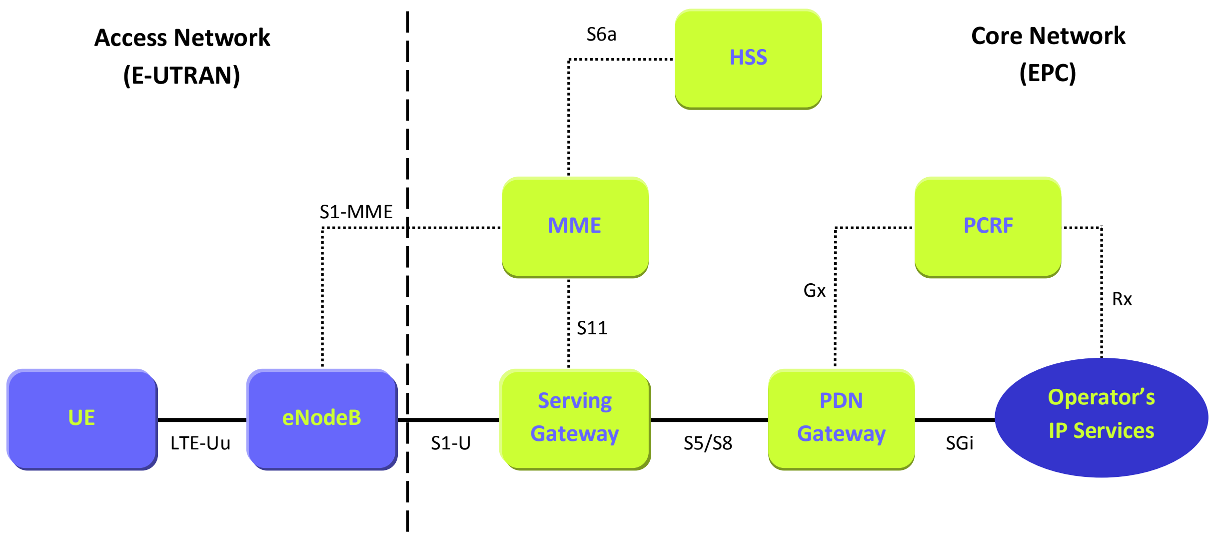


FIGURE 2 THE EPS NETWORK ELEMENTS.

The Core Network

The core network (called EPC) comprises the following logical elements:

1- Serving Gateway (S-GW): serves as the local mobility anchor for data bearers (service flows) and retains information about the bearers when the UE is in idle mode. The S-GW performs some administrative functions in the visited network such as collecting charging information (e.g. volume of sent and received user data). The S-GW serves as a mobility anchor for other 3GPP technologies (e.g. GSM, UMTS).

2- PDN Gateway (P-GW): responsible for allocation of IP address to the UE, QoS enforcement and flow-based charging according to PCRF rules. The P-GW filters downlink user IP packets into different bearers depending on QoS classification. The P-GW serves as a mobility anchor for non-3GPP technologies (e.g. CDMA2000, WiMAX).

3- Mobility Management Entity (MME): this is the control node that processes signaling between the UE and the core network. The protocols between the UE and the core network are known as Non-Access Stratum (NAS) protocols. The MME manages establishment, maintenance and release of bearers. It also manages the establishment of the connection and security between the UE and the network.

4- Policy Control Enforcement Function (PCRF): responsible for policy control decision making. The PCRF provides QoS authorization.

5- Home Subscriber Server (HSS): The HSS contains the subscriber profile such as QoS profile, access restriction and roaming capabilities. Furthermore, the HSS holds information such as to which MME the UE is attached. The HSS may include an Authentication Center (AuC) which generates authentication vectors and security keys.

The Access Network

The Access Network comprises the eNodeBs which are interconnected through an interface called X2, and to the EPC through the S1 interface (S1-MME to the MME and S1-U to the S-GW). The protocols between the eNodeB and the UE are known as Access Stratum (AS) protocols. The X2 interface is used to transfer the UE context between eNodeBs to support mobility function.

The eNodeB is responsible for radio-related functions such as Radio Resource Management (RRM) which include admission control, mobility control, scheduling and dynamic resource allocation to the UE in both uplink and downlink; security by encrypting user data; and other functions to ensure efficient use of the radio interface such as IP packet header compression. By residing all radio control functions in the eNodeB, LTE increases efficiency and reduces latency. It increases the resiliency of the network by eliminating the need for a central controller for such functions as in prior 3GPP technologies.

LTE Technologies

To meet the requirements set above, LTE implements a number of technologies which are described below.

Multi-Carrier Based Air Interface

LTE air interface is based on Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink path and Single-Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink path as shown in Figure 3.

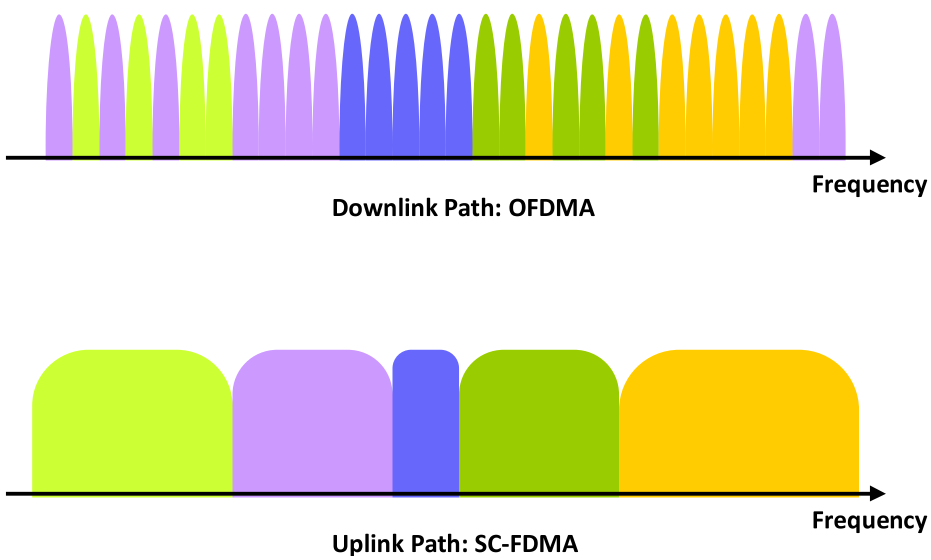


FIGURE 3 LTE ACCESS TECHNOLOGIES.

OFDMA subdivides the available bandwidth into a number of narrowband sub-carriers which are 'mutually orthogonal' (i.e. don't interfere with each other) each of which can carry independent information stream. This allows flexibility in a number of ways including:

1- Ability to schedule transmission in time and frequency domains: users can be assigned a number of sub-carriers at different instances in time.

2- Ability to operate in different channel bandwidth depending on spectrum allocations without impacting fundamental system parameters or equipment design.

3- Allows for flexible frequency planning techniques such as fractional frequency reuse where a subset of sub-carriers is used at cell edge or in areas of high interference in order to reduce interference levels and increase the frequency reuse factor.

4- Allows the design of low complexity receivers by limiting the need for equalization that is necessary on wideband single carrier systems like WCDMA.

5- Increases the robustness of the time-dispersive radio channel because of narrowband frequency sub-carriers constrain intersymbol interference.

6- Enables easier integration of advanced antenna technologies such as MIMO and beamforming to increase capacity or robustness of the radio signals.

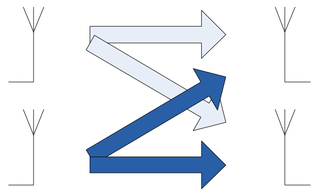
There are certain complexities that arise from using OFDMA, typically arising from high peak-to-average power ratio (PAPR) which requires linearization techniques on the transmitter and/or allowing for a larger power backoff from the 1dB compression point of the PA (12 dB versus about 8 dB for UMTS and only 2-3 dB for GSM). In order to allow for lower cost devices, LTE implements SC-FDMA for the uplink path, putting less demanding requirements of the PA design for mobile terminals and therefore reducing cost and design complexity.

Multi-Antenna Technologies

Multi-antenna technologies are a key element to meeting LTE's requirements on transmission rates and spectral efficiency. These technologies, specifically Multiple Input Multiple Output (MIMO), use the spatial dimension of the wireless propagation channel to increase the capacity of the wireless link and the robustness of the radio signal.

The use of several receive antennas has long been a standard on wireless base stations and the resulting benefit achieved by diversity reception reduces fading and increases signal quality. In addition to diversity reception, LTE implements diversity transmission where the same information is transmitted on multiple antennas. This has similar benefits to receive diversity and works to reduce fading and increase the robustness of the wireless channel. A third technique involves transmitting different information bit streams on separate antennas. This technique is commonly known as spatial multiplexing and is used to increase the capacity of the wireless propagation channel. The amount the capacity is increased is linearly proportional to the minimum number of transmit and receive antennas. Hence, a 2 x 2 system where two antennas are used for transmission and two for reception as shown in Figure 4 has the theoretical ability to double the capacity of the channel. In practice, interference and degradation of signal quality combine to reduce this maximum benefit.

Vendors can differentiate their product offerings by the number of supported antennas as well as the MIMO algorithms used to estimate the propagation channel characteristics and decode the transmitted signal in a sub-optimal setting typified by the characteristics of the deployment scenario which impacts the quality of the channel and the processing capability of the equipment. As fewer processing resources are available on the mobile terminal than the base station, less room to place multiple antennas to achieve low correlation of received signals and less power to drive multiple transmitters, mobile terminals are a main part of the gating factor on expanding the scalability of MIMO in wireless networks.



MIMO Capacity: Min (N_{Tx}, M_{Rx})

FIGURE 4 MULTIPLE INPUT MULTIPLE OUTPUT SPATIAL MULTIPLEXING.

PACKET SWITCHED RADIO INTERFACE

As already noted, LTE features a flat-IP architecture which separates it from existing 3GPP standards that include circuit-switched connection-oriented protocols to accommodate voice traffic.

LTE implements a number of techniques that maximize utilization of the fading nature of the wireless channel and the packet nature of its protocols. It is possible to transmit short packets with similar duration as the coherence time of the fast fading channel are possible which implies tight coupling between the physical layer (PHY) and the medium access control layer (MAC). This is achieved through a set of techniques that collectively comprise 'cross-layer optimization.' Hence, LTE scheduling is possible in both the time and frequency domains (i.e. a set of frequency sub-carriers is assigned to a user at different time intervals). Fast channel state feedback and dynamic link adaptation (selection of modulation and coding) are also featured. MIMO adaptation to suit the propagation channel by selecting the best MIMO mode is possible as well.

CONCLUSIONS

The rapid growth of data services and the convergence of the Internet with mobile technologies necessitated a new mobile system architecture that combines the latest technical innovations to meet the demand for voracious demand for data applications brought about by prevalence of large screen mobile devices. LTE is a technology developed with that view in mind. It therefore implements a packet-switched connection-less architecture to accommodate data services and features an efficient air interface that combines the latest innovations in capacity enhancing techniques such as link adaptation and MIMO technologies.

As a 3GPP standard LTE has received the full attention of the mobile operators. It promises to be a major element in resolving the capacity crunch facing these operators as consumer demand for data services expands.

ABBREVIATIONS AND ACRONYMS

3GPP	3rd Generation Partnership Project
EPC	Evolved Packet Core
EPS	Evolved Packet System
FDD	Frequency Division Duplex
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control Layer
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NAS	Non-Access Stratum
OFDMA	Orthogonal Frequency Division Multiple Access
PA	Power Amplifier
PCRF	Policy Control Enforcement Function
PDN	Packet Data Network
P-GW	Packet Data Network Gateway
PHY	Physical Layer
RRM	Radio Resource Management
Rx	Receiver
SAE	System Architecture Evolution
S-GW	Serving Gateway
TDD	Time Division Duplex
Tx	Transmitter
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
WCDMA	Wideband Code Division Multiple Access

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