

3GPP Long Term Evolution: Paving the Way towards Next 4G

David Martín-Sacristán, Jose F. Monserrat, Jorge Cabrejas-Peñuelas, Daniel Calabuig,
Salvador Garrigas and Narcís Cardona

Instituto de Telecomunicaciones y Aplicaciones Multimedia (iTEAM)

Universidad Politécnica de Valencia

Building 8G, access D, Camino de Vera s/n 46022 Valencia (SPAIN)

Corresponding author: jomondel@iteam.upv.es

Abstract

Long Term Evolution (LTE) is the new standard recently specified by the 3GPP in the next step forward towards fourth generation mobile. This paper presents the main technical features of this standard as well as its performance in terms of peak bit rate and average cell throughput, among others. LTE entails a big technological improvement as compared with previous 3G standard. However, this paper also demonstrates that LTE performance does not fulfil the technical requirements established by ITU-R to classify one radio access technology as a member of the IMT-Advanced family of standards. That is why, in addition to analyzing comparatively these very ambitious goals, this paper describes the procedure followed by the 3GPP to cope with these challenging requirements. By means of the design and optimization of some new radio access techniques and a further evolution of the system, the 3GPP is currently laying down the foundations of the future LTE-Advanced standard, the 3GPP candidate for 4G. This paper offers a brief insight into all these technological trends.

Keywords: LTE, IMT-Advanced, 4G, Performance, 3GPP

1. Introduction

In the last years, technology evolution in mobile communications is mainly motivated by three relevant agents: (1) the market globalization and liberalization and the increasing competence among vendors and operators coming from this new framework, (2) the popularization of IEEE 802 technologies within the mobile communications sector and, finally, (3) the exponential increase in the demand for advanced telecommunication services.

Concerning the last item, the envisaged applications to be supported by current and future cellular systems include Voice over IP (VoIP), videoconfer-

ence, push-to-talk over cellular (PoC), multimedia messaging, multiplayer games, audio and video streaming, content download of ring tones, video clips, Virtual Private Network (VPN) connections, web browsing, email access, File Transfer Protocol (FTP), etc. All these applications can be classified in several ways based on the QoS treatment that they require. Some of them are real-time and delay-sensitive, like voice and videoconference, while some others require integrity, high data-rate, and are sensitive to latency (like VPN and FTP). The simultaneous support of applications with different QoS requirements is one of the most important challenges that cellular systems are facing. At the same time, the spectrum scarcity makes that new wideband cellular systems are designed with very high spectral efficiency.

It is precisely this increasing market demand and its enormous economic benefits, together with the new challenges that come with the requirements in higher spectral efficiency and services aggregation, what raised the need to allocate new frequency channels to mobile communications systems. That is why the ITU-R WP 8F started in October 2005 the definition of the future Fourth Generation Mobile (4G), also known as International Mobile Telecommunications (IMT)-Advanced, following the same model of global standardization used with the Third Generation, IMT-2000. The objective of this initiative is to specify a set of requirements in terms of transmission capacity and quality of service, in such a way that if a certain technology fulfils all these requirements it is included by the ITU in the IMT-Advanced set of standards. This inclusion firstly endorses technologies and motivates operators to invest in them, but furthermore it allows these standards to make use of the frequency bands specially designated for IMT-Advanced, what entails a great motivation for mobile operators to increase their offered services and transmission capacity.

The race towards IMT-Advanced was officially started in March 2008, when the Circular Letter was distributed asking for the submission of new technology proposals [1]. Previous to this official

call, the 3rd Generation Partnership Project (3GPP) established the Long Term Evolution (LTE) standardization activity as an ongoing task to build up a framework for the evolution of the 3GPP radio technologies, concretely UMTS, towards 4G. The 3GPP divided this work into two phases: the former concerns the completion of the first LTE standard (Release 8), whereas the latter intends to adapt LTE to the requirements of 4G through the specification of a new technology called LTE-Advanced (Release 9 and 10). Following this plan, in December 2008 3GPP approved the specifications of LTE Release 8 which encompasses the Evolved UTRAN (E-UTRAN) and the Evolved Packet Core (EPC). Otherwise, the LTE-Advanced Study Item was launched in May 2008, expecting its completion in October 2009 according to the ITU-R schedule for the IMT-Advanced process. In the meantime, research community has been called for the performance assessment of the definitive LTE Release 8 standard.

Actually, several papers deal with the performance evaluation of LTE. However, up to date this assessment has been partially done because of one of these two reasons. First, some of these works only focused on the physical layer, leaving out the retransmission processes and error correction [2]-[4]. System level analysis need MAC layer performance information and cannot be carried out with only a physical layer characterization. Second, other papers assessing the performance of LTE radio access network assumed ideal channel estimation, which results in an optimistic estimation of LTE capacity [5]-[7].

This paper describes the main characteristics of LTE Release 8 and evaluates LTE link level performance considering a transmission chain fully compliant with LTE Release 8 and including realistic HARQ and turbo-decoding. Besides, the capacity of LTE systems is analyzed in terms of maximum achievable throughput and cell capacity distribution in a conventional scenario. These studies allow having a rough idea on the benefits and capabilities of the new standard. Finally, this paper offers an overview of the current research trends followed by 3GPP in the definition process of LTE-Advanced thus foreseeing the main characteristics of next generation mobile.

2. LTE Release 8 Technical Overview

3GPP Long Term Evolution is the name given to the new standard developed by 3GPP to cope with the increasing throughput requirements of the market. LTE is the next step in the evolution of 2G and 3G systems and also in the provisioning of quality levels similar to those of current wired networks.

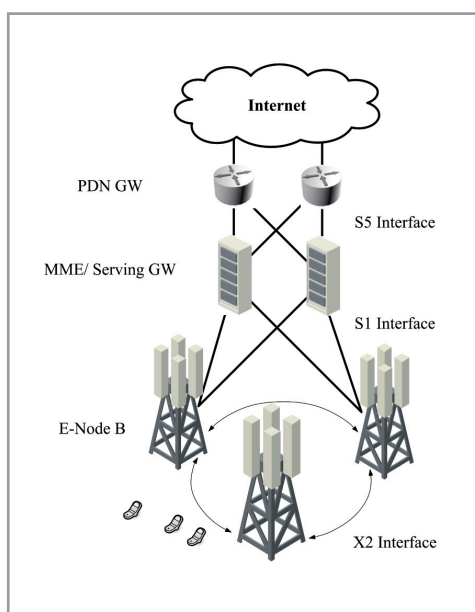
3GPP RAN working groups started LTE/EPC standardization in December 2004 with a feasibility study for an evolved UTRAN and for the all IP ba-

sed EPC. This is known as the Work Item phase. In December 2007 all LTE functional specifications were finished. Besides, EPC functional specifications reached major milestones for interworking with 3GPP and CDMA networks. In 2008 3GPP working groups were running to finish all protocol and performance specifications, being these tasks completed in December 2008 hence ending Release 8.

Among others, LTE design targets are: peak data rates of 100 Mbps in downlink and 50 Mbps in uplink, mobility up to 350 km/h, spectrum flexibility, seamless coexistence with previous technologies and reduced complexity and cost of the overall system.

To meet these requirements, a combination of a new system architecture together with an enhanced radio access technology was incorporated in the specifications.

LTE is the 3GPP framework for the evolution towards 4G



■ **Figure 1.** *The linear time variant model*

2.1 Architecture

There are different types of functions in a cellular network. Based on them, network can be split into two parts: a radio access network part and a core network part. Functions like modulation, header compression and handover belong to the access network, whereas other functions like charging or mobility management are part of the core network. In case of LTE, the radio access network is E-UTRAN and the core network EPC.

Radio access network

The radio access network of LTE is called E-UTRAN and one of its main features is that all services, including real-time, will be supported over shared packet channels. This approach will achieve increased spectral efficiency which will turn into higher system capacity with respect to current UMTS and HSPA. An important consequence of

The main philosophy behind LTE is minimizing the number of nodes.

using packet access for all services is the better integration among all multimedia services and among wireless and fixed services.

The main philosophy behind LTE is minimizing the number of nodes. Therefore the developers opted for a single-node architecture. The new base station is more complicated than the Node B in WCDMA/HSPA radio access networks, and is consequently called E-Node B (Enhanced Node B). The main functions of the E-Node B are related to radio resource management.

Core network

The new core network is a radical evolution of the one of third generation systems and it only covers the packet-switched domain. Therefore it has a new name: Evolved Packet Core.

Following the same philosophy as for the E-UTRAN, the number of nodes is reduced. EPC divides user data flows into the control and the data planes. A specific node is defined for each plane plus the generic gateway that connects the LTE network to the internet and other systems. Even though it is expected that the EPC follows a single-node architecture, i.e. all functions are in one node called advanced Gateway (aGW), the EPC comprises several functional entities:

- The MME (Mobility Management Entity): is responsible for the control plane functions related to subscriber and session management
- The Serving Gateway: is the anchor point of the packet data interface towards E-UTRAN. Moreover, it acts as the routing node towards other 3GPP technologies.
- The PDN Gateway (Packet Data Network): is the termination point for sessions towards the external packet data network. It is also the router to the Internet.
- The PCRF (Policy and Charging Rules Function): controls the tariff making and the IP Multimedia Subsystem (IMS) configuration of each user.

The overall structure of LTE is shown in Figure 1.

2.2 Radio access fundamentals

The most important technologies included in the new radio access network are Orthogonal Frequency Division Multiplexing (OFDM), multi-dimensional (time, frequency) dynamic resource allocation and link adaptation, Multiple Input Multiple Output (MIMO) transmission, turbo coding and hybrid Automatic Repeat reQuest (ARQ) with soft combining. These technologies are shortly explained in the following paragraphs.

OFDM

Orthogonal Frequency Division Multiplexing is a kind of multi-carrier transmission technique with a relatively large number of subcarriers. OFDM offers a lot of advantages. First of all, by using a

multiple carrier transmission technique, the symbol time can be made substantially longer than the channel delay spread, which reduces significantly or even almost removes the inter-symbol interference (ISI). In other words, OFDM provides a high robustness against frequency selective fading. Secondly, due to its specific structure, OFDM allows for low-complexity implementation by means of Fast Fourier Transform (FFT) processing. Thirdly, the access to the frequency domain (OFDMA) implies a high degree of freedom to the scheduler. Finally, it offers spectrum flexibility which facilitates a smooth evolution from already existing radio access technologies to LTE.

In the FDD mode of LTE each OFDM symbol is transmitted over subcarriers of 15 or 7.5 kHz. One subframe lasts 1 ms, divided in two 0.5 ms slots, and contains several consecutive OFDM symbols (14 and 12 for the 15 and 7.5 kHz modes respectively).

In the uplink, Single Carrier Frequency Division Multiple Access (SC-FDMA) is used rather than OFDM. SC-FDMA is also known as DFT-spread OFDM modulation. Basically, SC-FDMA is identical to OFDM unless an initial FFT is applied before the OFDM modulation. The objective of such modification is to reduce the power peak to average ratio, thus decreasing the power consumption in the user terminals.

Multidimensional dynamic resource allocation and link adaptation

In LTE, both uplink and downlink transmission schemes can assign smaller, non-overlapping frequency bands to the different users, offering frequency division multiple access (FDMA). This assignment can be dynamically adjusted in time and is referred to as scheduling. Accordingly, the LTE resources can be represented as a time-frequency grid. The minor element of this grid is called resource element and consists of one subcarrier during an OFDM symbol. However, the minor LTE resource allocation unit is the resource block that consists of 12 subcarriers during one slot.

Link adaptation is closely related to scheduling and deals with how to set the transmission parameters of a radio link to handle variations of the radio-link quality. This is achieved in LTE through adaptive channel coding and adaptive modulation. Specifically, in LTE available modulations are QPSK, 16QAM and 64QAM.

MIMO

One of the most important means to achieve the high data rate objectives for LTE is multiple antenna transmission. LTE supports one, two or four transmit antennas and one, two or four receive antennas. Multiple antennas can be used in different ways: to obtain additional transmit/receive diversity or to get spatial multiplexing increasing the data rate by creating several parallel channels if conditions allow to.

Turbo coding

In order to correct bit errors, introduced by channel variations and noise, channel coding is utilized. In case of the LTE downlink shared channel (DL-SCH) a turbo encoder with rate 1/3 is used, followed by puncturing to increase the coding rate to the desired level. In each subframe of 1 ms, one or two (with multi-codeword MIMO) codewords can be coded and transmitted.

Hybrid ARQ with soft combining

Hybrid ARQ with soft combining is a technique that deals with the retransmission of data in case of errors. In an ARQ scheme, the receiver uses an error-detecting code to check if the received packet contains errors or not. The transmitter is informed by a NACK or ACK respectively. In case of a NACK, the packet is retransmitted.

A combination of forward error correction (FEC) and ARQ is known as hybrid ARQ. Most practical hybrid ARQ schemes are built around a CRC code for error detection and a turbo code for error correction, as it is the case of LTE.

In hybrid ARQ with soft combining, the erroneously received packet is stored in a buffer and later combined with the retransmission(s) to obtain a single packet that is more reliable than its constituents. In LTE full incremental redundancy (IR) is applied, which means that the retransmitted packets are typically not identical with the first transmission but carry complementary information.

3. Analysis of LTE Performance

Different methods can be used to assess the performance of a mobile technology. Each method is best suited for a particular kind of performance assessment. For instance, analytical methods or inspections are valid to evaluate peak data rates or peak spectral efficiencies. However, a deeper performance analysis requires the usage of simulation. Simulators are usually divided in two classes: link level simulators and system level simulators. Link level simulators are used to emulate the transmission of information from a unique transmitter to a unique receiver modeling the physical layer with high precision. They include models for coding/decoding, MIMO processing, scrambling, modulation, channel, channel estimation and equalization, etc. System level simulators emulate the operation of a network with a number of cells and several users per cell.

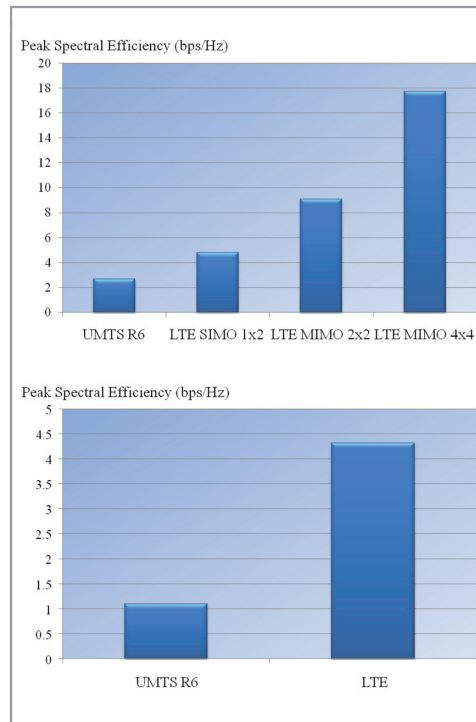
In this kind of simulators, higher level functions are included for call admission control, scheduling, power control, etc. while link to system level models are used to facilitate the emulation of each radio link.

This section present some results obtained from both types of simulators fully developed by the iTEAM research institute. This assessment allows

getting an insight into to which extent LTE implies a revolution in comparison with UMTS. Besides, as shown in next section, these results demonstrate that LTE is quite close to the requirements established for the fourth generation mobile, although further improvements are expected in LTE-Advanced.

3.1 Peak spectral efficiency

The peak spectral efficiency is the highest theoretical data rate assignable to a single mobile user divided by the allocated bandwidth. The highest data rate is calculated as the received data bits assuming error-free conditions and excluding radio resources that are used for control issues and guard bands. At the end, the radio access technology is classified as more or less powerful according to the achievable efficiency what makes this measurement perfect for comparative purposes.



■ **Figure 2.** LTE peak spectral efficiencies in LTE is the 3GPP framework for the evolution towards 4G

Assuming a transmission bandwidth of 10MHz the maximum achievable rates in downlink are: 48 Mbps for SIMO 1x2, 91.2 Mbps for MIMO 2x2 and 177.6 Mbps for MIMO 4x4. The resulting peak spectral efficiencies are 4.8, 9.12 and 17.76 b/s/Hz for the considered multi-antenna schemes. In uplink with SIMO 1x2 the maximum achievable rate is 43.2 Mbps with a transmission bandwidth of 10 MHz. Thus, the peak spectral efficiency is 4.32 b/s/Hz.

The calculated peak spectral efficiencies of LTE are depicted in Figure 2 for both downlink and uplink together with the efficiencies of UMTS

The maximum achievable bit rate in downlink is 177.6 Mbps for MIMO 4x4

Common parameters		
Bandwidth	10 MHz (50RB)	
Channel	EPA model, 5Hz Doppler frequency	
Central frequency	2.5 GHz	
MCS	CQI 4 – 15	
Multi-antenna schemes	DL	SIMO 1x2, MIMO 2x2 / 4x4
	UL	SIMO 1x2 / 1x4
Control channels overhead	DL	2 OFDM symbols per subframe
	UL	not considered
System level parameters		
ISD	500m	
Cell deployment	Omnidirectional cells, reuse 1 factor	
Pathloss	130.2+37.6 log10(d(km))	
Shadowing	lognormal, $\sigma=8$ dB	
Transmission power	43dBm	
Interf. transmission power	40 dBm	
Noise spectral density	-174 dBm/Hz	

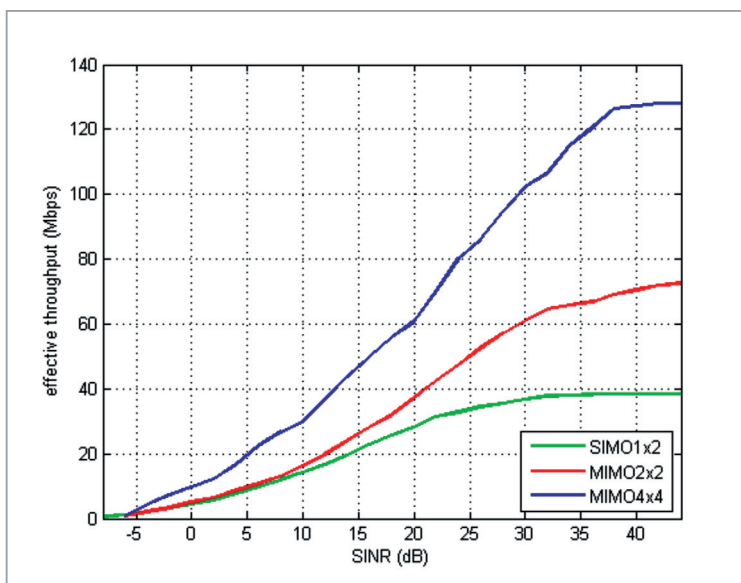
■ **Table 1.** Simulation parameters

Release 6, i.e. including HSDPA and HSUPA. From this peak spectrum efficiency it can be seen that LTE with 20MHz meets and exceeds the 100Mbps downlink and 50Mbps uplink initial targets.

Besides, the comparison with UMTS demonstrates that LTE is a major step forward in mobile radio communications. With these achievable data rates mobile systems will give a greater user experience with the capability of supporting more demanding applications.

3.2 LTE link level performance

Based on link level simulations it can be assessed the relation between effective throughput (co-



■ **Figure 3.** Link level evaluation of throughput vs SINR in LTE downlink

rectly received bits per time unit) and signal to noise plus interference ratio (SINR). Simulations assessed for this paper used 10 MHz of bandwidth for both downlink and uplink. This bandwidth is equivalent to 50 LTE resource blocks. The evaluation was focused on the performance experienced by a pedestrian user and hence the user mobility model used was the extended pedestrian A model [10] with a Doppler frequency of 5Hz. The central frequency has been set to 2.5GHz, the most likely band for initial LTE deployment. A set of modulation and coding schemes has been selected from the CQI table included in LTE specifications [11]. This set was selected by 3GPP to cover the LTE SINR dynamic margin with approximately 2 dB steps between consecutive curves. A distinction from other studies is that channel estimation was realistically calculated at the receivers. In order to exploit the multi-antenna configuration at the receiver side, minimum mean-square error (MMSE) equalization was considered. The remaining parameters considered in the simulations are summarized in Table 1.

Concerning LTE downlink, different multi-antenna configurations were modeled including SIMO 1x2, MIMO 2x2 and MIMO 4x4. Simulated MIMO scheme followed the open loop spatial multiplexing scheme as specified by the 3GPP [12], the number of codewords were 2 and the number of layers was equal to the number of transmit antennas, i.e. 2 and 4. Additionally, the multiple channels among antennas were supposed uncorrelated. Control channel and signals overhead were taken into account and hence the first two OFDM symbols in each subframe were reserved for control channels. Besides, reference signals were emulated in detail, although neither broadcast information nor synchronization signals overhead were considered.

In the uplink, two different multi-antenna configurations were simulated: SIMO 1x2 and SIMO 1x4. The multiple channels among antennas were supposed uncorrelated too. Nowadays, the LTE standard does not allow MIMO in uplink so that MIMO schemes were not simulated. Therefore, as established in the 3GPP specifications [13], only one codeword was considered. Moreover, 12 of the 14 available SC-FDMA symbols in a subframe were occupied by codified data since the other 2 were reserved for reference signals needed for the channel estimation at the receiver. Taking into account these assumptions and parameters, a set of simulations was performed whose results are shown in Figure 3 for LTE downlink and in Figure 4 for LTE uplink. In both figures it can be observed that the maximum throughputs are not equal to the peak throughputs previously calculated. The reason is that both in downlink and uplink, the highest coding rate used is not 1 but around 0.96. Besides, in downlink control channels overhead reduces the maximum achievable data rate, which was not considered in the peak spectral efficiency calculation due to its definition.

In LTE downlink, according to the results shown in Figure 3, MIMO 4x4 scheme provides a clearly better performance than the other schemes for almost all the useful SINR margin. Nevertheless, MIMO 2x2 scheme does not provide an important performance improvement until SINR reaches a value of 15 dB. Also, it can be observed that improvement factor in peak throughput due to MIMO schemes is far from being 2 or 4. Instead, throughput is multiplied by 1.7 and 3.6 in MIMO 2x2 and MIMO 4x4 respectively. This is basically due to the higher quantity of reference signals needed in the MIMO schemes.

In LTE uplink, there is not any throughput gain when using more receiver antennas. But a non-negligible SINR gain can be achieved. This gain is about 5 dB for a throughput of 20 Mbps. Note that in SIMO 1x4 maximum rate is achieved 10 dB before than in SIMO 1x2.

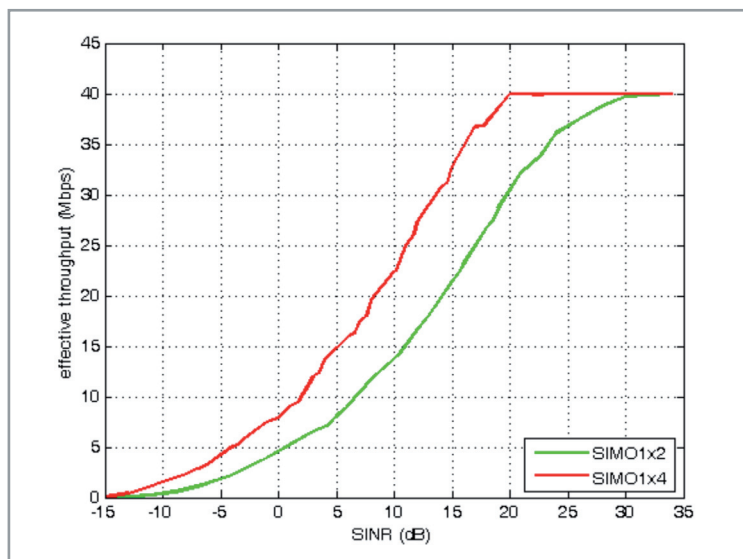
3.3 Average spectral efficiency

Average spectral efficiency is calculated as the mean user throughput of all users (the number of correctly received bits over a certain period of time) normalized by the overall cell bandwidth and divided by the number of cells.

In order to calculate this cell related spectral efficiency a simplified analytical approach has been used. First, using a Montecarlo simulation, it has been obtained the SINR distribution in a cell. Parameters of the considered scenario are shown in Table I. Using the SINR distribution and the throughput-SINR relation previously provided, the throughput distribution in the cell can be easily calculated, and hence the average throughput and average spectral efficiency. However, it is necessary to remind that link level curves are referred to mean SNR values, therefore that option would not take into account link adaptation gain. Following the proposed approach, average spectral efficiency obtained for SIMO 1x2 is 1.16 bps/Hz/cell, for MIMO 2x2 1.54 bps/Hz/cell and for MIMO 4x4 2.70 bps/Hz/cell. It is worth highlighting that these results have been calculated following ITU-R indications. However, this average spectral efficiency calculation is not taking into account the potential gain in cell throughput achieved due to multi-user diversity, which is one of the main characteristics of OFDMA systems. Therefore, it can be said that this average spectral efficiency is the minimum mean capacity of a LTE system with inter site distance of 500m.

4. LTE-Advanced and the Fourth Generation Mobile

The process of defining the future IMT-Advanced family was started with a Circular Letter issued by ITU-R calling for submission of candidate Radio Access Technologies (RATs) for IMT-Advanced [1]. However, all documents available in that moment concerning IMT-Advanced did



■ Figure 4. Link level evaluation of throughput vs SINR in LTE uplink

not specify any new technical details about the properties of future 4G systems. Instead, they just reference the Recommendation M.1645 [8], in which the objectives of the future development of IMT-Advanced family were barely defined: to reach 100 Mb/s for mobile access and up to 1 Gb/s for nomadic wireless access. Unfortunately, it was not until November 2008 when the requirements related to technical performance for IMT-Advanced candidate radio interfaces were described [9].

Just after receiving the Circular Letter, the 3GPP organized a workshop on IMT-Advanced where the following decisions were made:

- LTE-Advanced will be an evolution of LTE. Therefore LTE-Advanced must be backward compatible with LTE Release 8.
- LTE-Advanced requirements will meet or even exceed IMT-Advanced requirements following the ITU-R agenda.
- LTE-Advanced should support significantly increased instantaneous peak data rates in order to reach ITU requirements. Primary focus should be on low mobility users. Moreover, it is required a further improvement of cell edge data rates.

With these clear objectives, and without knowing the final technical requirements yet, 3GPP defined a bullets list with the first requirements for LTE-Advanced and some technical proposals.

Besides, it was decided to officially gather and approve them in the technical report TR 36.913 [14]. The remaining of this section deals with both aspects: requirements and technical proposals for LTE-Advanced.

4.1 LTE-Advanced requirements

The requirement specification list was included in

The peak data rate for LTE-Advanced is 1Gbps for downlink.

		Requirements LTE TR 25.913	Requirement ITU-R M.2134	Requirements LTE-A TR 36.913
Peak Data Rate (Gbps)		0.1	1	1 - (DL) 0.5 - (UL)
Latency		C-Plane <100ms U-Plane <10ms	C-Plane <100ms U-Plane <10ms	C-Plane <50ms U-Plane <10ms
Peak Spectral Efficiency (bps/Hz)	DL	5 (1x2)	15 (4x4)	30 (8x8)
	UL	2.5 (1x2)	6.75 (2x4)	15 (4x4)
Average Spectral Efficiency (bps/Hz/cell)	DL	R 1.54 (2x2) 2.70 (4x4)	2.2 (4x2)	2.4 (2x2) 3.7 (4x4)
	UL	R 0.8 (1x2)	1.4 (2x4)	1.2 (1x2) 2.0 (2x4)
Cell Edge User Spectral Efficiency (bps/Hz/cell/user)	DL	R 0.04 (2x2) 0.05 (4x4)	0.06 (4x2)	0.07 (2x2) 0.12 (4x4)
	UL	R 0.02 (1x2)	0.03 (2x4)	0.04 (1x2) 0.07 (2x4)
Mobility		up to 350 km/h	up to 350 km/h	up to 350 km/h
Bandwidth		up to 20 MHz	> 40 MHz	up to 100 MHz

■ **Table 2.** Requirements related to technical performance

TR 36.913 too. Although it is expected a list extension, these are some of the current agreements on the requirements for LTE-Advanced [14]:

- Peak data rate of 1 Gbps for downlink (DL) and 500 Mbps for uplink (UL).
- Regarding latency, in the C-plane the transition time from Idle to Connected should be lower than 50 ms. In the active state, a dormant user should take less than 10ms to get synchronized and the scheduler should reduce the U-plane latency at maximum.
- The system should support downlink peak spectrum efficiency up to 30 bps/Hz and uplink peak spectrum efficiency of 15 bps/Hz with an 8x8 MIMO configuration in DL and 4x4 in UL.
- The 3GPP defined a base coverage urban scenario with inter-site distance of 500m and pedestrian users. Assuming this scenario, average user throughput in DL must be 2.4 bps/Hz/cell with MIMO 2x2 and 3.7 bps/Hz/cell with MIMO 4x4, whereas in UL the target average throughput is 1.2 bps/Hz/cell and 2.0 bps/Hz/cell with SIMO 1x2 and MIMO 2x4, respectively.
- If in the same scenario 10 users are dropped in a cell, the 5% point of CDF of the user throughput normalized with the overall cell bandwidth (cell edge user throughput) shall be 0.07 bps/Hz/cell/user in DL 2x2 and 0.12 in DL 4x4. In the UL, this cell edge user throughput must be 0.04 bps/Hz/cell/user with SIMO 1x2 and 0.07 with MIMO 2x4.
- The mobility and coverage requirements are identical to LTE Release 8. There are only dif-

ferences with indoor deployments that need additional care in LTE-Advanced.

- In terms of spectrum flexibility, the LTE-Advanced system will support scalable bandwidth and spectrum aggregation with transmission bandwidths up to 100 MHz in DL and UL.
- LTE-Advanced must guarantee backward compatibility and interworking with LTE and with other 3GPP legacy systems.

Table 2 summarizes the list of requirements established by ITU-R and 3GPP allowing a direct comparison among LTE, 4G and LTE-Advanced. In the table, R denotes that these values come from simulation obtained by using the simulation platform previously described not from specifications. According to this table, it can be concluded that LTE-Advanced is being designed to be a strong candidate for next 4G, since it fulfils or even exceeds all IMT-Advanced requirements.

4.2 LTE-Advanced technical proposals

LTE Release 8 can already fulfill some of the requirements specified for IMT-Advanced systems. However, it is also clear that there are more challenging requirements under discussion in the 3GPP, which would need novel radio access techniques and system evolution. The 3GPP working groups, mainly RAN1 working on the physical layer, are currently evaluating some techniques to enhance LTE Release 8 performance. This section offers an overview of some of these proposals.

Support of wider bandwidth

A significant underlying feature of LTE-Advanced will be the flexible spectrum usage. The framework for the LTE-Advanced air-interface technology is mostly determined by the use of

wider bandwidths, potentially even up to 100 MHz, non-contiguous spectrum deployments, also referred to as spectrum aggregation, and a need for flexible spectrum usage.

In general OFDM provides a simple means to increase bandwidth: adding additional subcarriers. Due to the discontinuous spectrum reserved for IMT-Advanced, the available bandwidth might also be fragmented. Therefore, the user equipments should be able to filter, process and decode such a large variable bandwidth. The increased decoding complexity is one of the major challenges of this wider bandwidth.

Concerning the resource allocation in the E-Node B and the backward compatibility, minimum changes in the specifications will be required if scheduling, MIMO, Link Adaptation and HARQ are performed over groups of carriers of 20MHz. For instance, a user receiving information in 100MHz bandwidth will need 5 receiver chains, one per each 20MHz block.

Uplink transmission scheme

In the uplink, the UE transmit power is an important factor limiting the use of very high data rates. Hence, non-symmetric UL/DL bandwidths may be necessary. Another challenging issue is related to the usage of the UL DFT-spread OFDM modulation. If spectrum aggregation is used the requirement established by this modulation of allocating contiguous subcarriers would be very hard to satisfy. It is envisaged that for very high UL data rates a more general kind of OFDM transmission than the DFT-spread OFDM may be more beneficial in terms of performance and flexibility to match the available spectrum. Several alternatives are now under discussion in the 3GPP and it is expected that one additional uplink access scheme will be included in the LTE-Advanced specification.

Coordinated multiple point transmission and reception

Coordinated multi point transmission and reception is considered for LTE-Advanced as one of the most promising techniques to improve the coverage of high data rates, hence increasing average cell throughput. It consists in coordinating the transmission and reception of signal from/to one UE in several geographically distributed points. So far, the discussions have focused on classifying the different alternatives and identifying their constraints. Potential impact on specifications comprises three areas: feedback and measurement mechanisms from the UE, pre-processing schemes and reference signal design.

Relaying functionality

Relaying can be afforded from three different levels of complexity. The simplest one is the Layer 1 relaying, i.e. the usage of repeaters. Repeaters receive the signal, amplify it and retransmit the information thus covering black holes inside cells. Terminals can make use of the repeated

and direct signals. However, in order to combine constructively both signals there should be a small delay, less than the cyclic prefix, in their reception.

In Layer 2 relaying the relay node has the capability of controlling at least part of the RRM functionality. In some slots the relay node acts as a user terminal being in the subsequent slot a base station transmitting to some users located close to the relay.

Finally, Layer 3 relaying is conceived to use the LTE radio access in the backhaul wireless connecting one E-Node B with another E-Node B that behaves as a central hub. This anchor E-Node B routes the packets between the wired and wireless backhaul, acting like an IP router.

Enhanced Multiple-Input Multiple-Output Transmission

Another significant element of the LTE-Advanced technology framework is MIMO, as in theory it offers a simple way to increase the spectral efficiency. The combination of higher order MIMO transmission, beamforming or Multi-User (MU) MIMO is envisaged as one of the key technologies for LTE-Advanced.

In case of spectrum aggregation, the antenna correlation may be different in each spectrum segment given a fixed antenna configuration. Therefore, in LTE-Advanced one channel element may encompass both low correlation and high correlation scenarios simultaneously. Since MU-MIMO is more appropriated for high correlation scenarios than Single-User (SU) MIMO, to fully utilize the characteristics of different scattering scenarios both SU-MIMO and MU-MIMO should be simultaneously used.

5. Conclusions

LTE has been designed as a future technology to cope with next user requirements. In this paper two complete LTE Release 8 link and system level simulators have been presented together with several performance results. Based on these results, this paper concludes that LTE will offer peak rates of more than 150Mbps in the downlink and 40Mbps in the uplink with 10MHz bandwidth. Besides, in the downlink the minimum average throughput will be around 30Mbps, which represents a quite significant improvement in the cellular systems performance. As compared with current cellular systems, LTE entails an enhancement of more than six times the performance of HSDPA/HSUPA.

This paper has also given an initial insight into the new technical proposals currently under discussion in the framework of 3GPP. This analysis allows those who are interested in wireless communications to get aligned with the research community towards the definition and optimization of next fourth generation mobile.

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Biographies



David Martín-Sacristán (damargan@iteam.upv.es) received his M.S. degree in telecommunications engineering from the Polytechnic University of Valencia (UPV) in 2006. Nowadays, he is a Ph.D student in the Institute of Telecommunications and Multimedia Applications (iTEAM), UPV. His research interests are focused on beyond 3G networks including modeling and simulation, resource management and link adaptation.



Jose F. Monserrat (jomondel@iteam.upv.es) received his M.S. degree with High Honors and Ph.D. degree in electrical engineering from the Polytechnic University of Valencia (UPV) in 2003 and 2007, respectively. He was the recipient of the First Regional Prize of Engineering Studies in 2003 for his outstanding student record. He is currently an assistant professor in the Communications Department of the UPV. His research focuses on the application of complex computation techniques to Radio Resource Management strategies in mobile communications networks as HSDPA or LTE.



Jorge Cabrejas

(jorcabpe@iteam.upv.es) received the M.S. degree in Telecommunications Engineering from the Polytechnic University of Valencia (UPV), Valencia, Spain, in 2008. He is currently working in the

Mobile Communications Group, Institute of Telecommunications and Multimedia Applications (iTEAM), UPV. He is currently studying a Master's degree in Technologies, Systems and Communication networks. His research focuses on the study of new mobile communications networks such as LTE.



Daniel Calabuig

(dacaso@iteam.upv.es) received the M.S. degree in telecommunications engineering from the Polytechnic University of Valencia (UPV), Valencia, Spain, in 2005. He is currently working toward

the Ph.D. degree with the Mobile Communications Group, Institute of Telecommunications and Multimedia Applications (iTEAM), UPV. His current research interests include neural networks, optimization, and radio resource management.



Salvador Garrigas

(salgars1@iteam.upv.es) During his studies, he spent one year in Helsinki (Finland) working for the Helsinki University of Technology (TKK) in order to carry out his final project. After that,

he received his M.S. degree in telecommunications engineering from the Polytechnic Univer-

sity of Valencia (UPV), Valencia, Spain, in 2008. Nowadays, he is working for the Institute of Telecommunications and Multimedia Applications (iTEAM), UPV, where he is a member of the Mobile Communications Group. His research is focused on LTE.



Narcís Cardona

(ncardona@iteam.upv.es) was born in Barcelona, Spain. He received the M.S. degree in communications engineering from ETSE Telecommunications, Polytechnic University of Catalunya,

Barcelona, in 1990 and the Ph. D. degree in telecommunications from the Polytechnic University of Valencia (UPV), Valencia, Spain, in 1995.

Since October 1990, he has been with the Department of Communications, UPV, where he is the Head of the Mobile Communications Group, the Director of the Mobile Communications Master Degree, and the Assistant Director of the Research Institute on Telecommunications and Multimedia Applications (iTEAM). He has led several national research projects and has participated in some European projects, i.e., Networks of excellence, and other research forums in mobile communications. His current research interests include mobile channel characterization, planning and optimization tools for cellular systems, RRM techniques applied to personal communications, and broadcast cellular hybrid networks.

Dr. Cardona has been the Vice-Chairman of the COST273 Action and is currently in charge of the WG3 of COST2100 in the area of radio access networks. He was the Chairman of the Third International Conference on Wireless Communications Systems (ISWCS'06).