An Overview of Long Term Evolution Advanced

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Abstract

This paper offers an introduction to the mobile communication standard known as LTE Advanced, depicting the evolution of the standard from its roots and discussing several important technologies that help it evolve to accomplishing the IMT-Advanced requirements. A short history of the LTE standard is offered, along with a discussion of its standards and performance. LTE-Advanced details include brief history of the standard, technical requirements, as well as analysis on the physical layer, resource control, and performance.

Keywords

LTE, IMT-Advanced, LTE-Advanced, radio standards, physical layer, spectrum flexibility

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1 Introduction

LTE-Advanced is a 3GPP standard that describes technological advancements to the Long Term Evolution (LTE) a highly flexible radio interface that aims at bridging the gap between 3rd generation and 4th generation (4G) standards – described in IMT-Advanced (International Mobile Telecommunications) [1][3].
LTE Advanced does meet most of the standards for 4G deployment, though it is often described as 3.9G or pre-4G. However, LTE Advanced is capable of peak download data rates of 1 Gbps, with a wide transmissio

bandwidth, low C-plane latency, backwards compatibility, increased user throughput and spectrum flexibility.

While work on the LTE standard draws to an end, the direction switches to developing LTE advanced, also referred as 3GPP Release 10. LTE Advanced should be compatible with first release LTE (3GPP Release 8 equipment, and should share frequency bands with first release LTE, thus making it backwards compatible. 4G, it is estimated that 100 MHz bandwidth will offer data rates of 1 Gbps and while OFDM offers an easy way to increase bandwidth by adding additional subcarriers, the scheduler would have to include a mix of terminals. The 3GPP working groups looking at proposals for the standard have focused mainly on the physical layer; the topics analyzed included relay nodes, scalable system bandwidth exceeding 20 MHz, loca area optimization of air interface, flexible spectrum usage, diversity MIMO, etc. Ultimately, standardization is expected to be included in 3GPP Release 10 timeframe. The importance and timeframe of LTE Advanced will mainly depend on the success of LTE itself. LTE Advanced will be fully built on the existing LTE specification Release 10 and not be defined as a new specification series. Major enhancements to LTE were introduced in Release 10 after a correction and improvement phase in Release 9. Since LTE Advanced fulfills most ITU standards for 4G, the 3GPP work plan is similar to the schedule within ITU.

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2 LTE Overview

3GPP Long Term Evolution is the name given to the 3GPP standard required to deal with the increasing data throughput requirements of the market. Working groups from 3GPP RAN started to work on standardization for LTE in late 2004. By 2007, all LTE features related to its functionality were finished and by 2008, most protocol and performance specifications were finished and included in Release 8.

2.1 LTE Requirements

3GPP gathered all requirements for LTE [3GPP1]; some requirements are written in an absolute fashion – defining concepts from scratch – while others are meant in relation to UTRA nomenclature. In this context, the reference for UTRA baseline is the use of Release 6 HSDPA with 1x1 multi-antenna scheme for the downlink and Release 6 HSUPA with a 1x2 multi-antenna scheme for the uplink. Here are several LTE design parameters [Martin09]:

1. systems should support peak data rates of 100 Mbps in downlink and 50 Mbps in uplink, within a 20 MHz bandwidth or spectral efficiency values of 5 bps/Hz and 2.5 bps/Hz respectively.
2. downlink and uplink user throughput per MHz at the 5% point of the CDF; 2-3 times Release 6 HSPA.
3. downlink averaged use throughput per MHz at 3-4 times Release 6 HSDPA; uplink averaged user throughput per MHz at 2-3 times Release 6 Enhanced Uplink.
4. spectrum efficiency 3-4 times Release 6 HSDPA in downlink and 2-3 times Release 6 HSUPA in uplink, in a loaded network
5. mobility up to 350 km/h
6. spectrum flexibility, seamless coexistence with previous technologies and reduced complexity and cost of the overall system

In order to achieve these goals, LTE made use of a new system architecture combined with enhanced radio access technology. It divided network functions such as modulation, header compression and handover to the radio access network, while others such as charging, mobility management to the core network.

2.2 LTE Technological Components

In this section, several concepts related to radio access network are discussed in order to offer better understanding of the technology behind LTE.

1. OFDM. Orthogonal Frequency Division Multiplexing is a frequency division multiplexing scheme utilized as digital multi-carrier modulation method. In LTE OFDM, data is transmitted on numerous parallel narrow-band subcarriers. The symbol time can be much longer than the channel delay spread, which reduces inter-symbol interference. OFDM can also be implemented fairly easily with FFT (Fast Fourier Transform) processing. Moreover, this allows for spectrum flexibility, so that former technologies may progress easily to LTE. In the uplink, LTE uses SC-FDMA (Single Carrier Frequency Division Multiple Access) instead of OFDM. The difference between OFDM and SC-FDMA is the following: in OFDM, Fast Fourier transform is applied on the receiver side on each block of symbols and inverse FFT (IFFT) on the transmitter side. In SC-FDMA, both FFT and IFFT are applied on the transmitter and receiver side. Due to the fact that the uplink transmission power is much lower than the downlink transmission power, LTE makes good use of SC-FDMA, as it has a smaller peak-to-average power-ratio than the regular OFDM that implies less complex terminals [Martin09]

2. Spectrum Flexibility. LTE can operate in various frequency bands and can be deployed with different bandwidths so that a different spectrum may allow efficient migration from other radio technologies to LTE. LTE has an overall system bandwidth that extends from 1.4 MHz to 20 MHz (required for highest data rates). LTE can operate in both paired and unpaired spectrum by supporting both FDD (Frequency Division Duplex) and TDD (Time Division Duplex) [Parkvall09]

3. MIMO. Multiple-input and multiple-output is a form of smart antenna radio technology that entails the use of multiple antennas at both the transmitter and the receiver to improve performance. MIMO technology is very important for LTE to reach the data rates it targeted. All terminals support at least two receive antennas, which implies that networks can assume the presence of downlink receive diversity. LTE supports several advanced multi-antenna schemes such as transmit diversity, spatial multiplexing, and beam-forming [Parkvall09]

4. Link Adaptation. Adaptive coding and modulation refers to the matching of the modulation, coding and other signal and protocol parameters to the conditions on the radio link. In LTE, this is implemented by QPSK, 16 QAM and 64 QAM; coding rate varies from 0.07 to 0.93.

5. Turbo Codes. Turbo codes represent class of forward error detection codes, originally developed to push channel capacity to the maximum theoretical level. The LTE downlink shared channel uses a turbo encoder with rate 1/3; it is followed by rate matching to set the coding to intended levels. [Martin09]

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3 LTE-Advanced

This section presents an LTE-Advanced overview starting with a brief history of LTE evolution, a discussion of the most important requirements set by the 3GPP and techical information related to the physical layer, including DL and UL channels, OFDMA/SC-FDMA scheme, and radio interface.

3.1 LTE-Advanced Overview

ITU issued an invitation [ITUb] for radio-access technologies beyond IMT-2000 – also referred to as IMT-Advanced. Nevertheless, 3GPP was expecting this event to unfold and had already started a study on LTE-Advanced with the purpose of finding the requirements and technology components so that the evolution of LTE would meet the requirements of IMT-Advanced. The first step was to consider backwards

compatibility with the existent version of LTE; this implies that an LTE UE would see the LTE-Advanced network as an LTE network. Spectrum compatibility was required for a straightforward, low-cost progression to LTE-Advanced networks, similar to the evolution of WCDMA to HSPA. In addition to these parameters, LTE-Advanced was intended to match or exceed the standards set by the ITU for IMT-Advanced with regards to capacity, data rates and low-cost deployment [Parkvall09].

The features that ITU had chosen for IMT-Advanced were: 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; and 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).

After receiving the Circular Letter [ITUb] [Martin09], 3GPP held a workshop with regard to LTE-Advanced matching IMT-Advanced requirements and took several decisions.

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

3.2 LTE-Advanced Requirements

The requirements for LTE-Advanced are delineated in TR 36.913 [3GPPb]. The most important requirements are the following [Martin09]:

1. Peak data rate of 1 Gbps for downlink (DL) and 500 Mbps for uplink (UL).
2. Regarding latency, in the C-plane the transition time from Idle to Connected should be lower than 50ms. 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.
3. The system should support downlink peak spectral efficiency up to 30 bps/Hz and uplink peak spectral efficiency of 15 bps/Hz with an antenna configuration of 8 × 8 or less in DL and 4 × 4 or less in UL.
4. The 3GPP defined a base coverage urban scenario with inter-site distance of 500m and pedestrian users. Assuming this scenario, average user spectral efficiency in DL must be 2.4 bps/Hz/cell with MIMO 2 × 2, 2.6 bps/Hz/cell with MIMO 4 × 2 and 3.7 bps/Hz/cell with MIMO 4 × 4, whereas in UL the target average spectral efficiency is 1.2 bps/Hz/cell and 2.0 bps/Hz/cell with SIMO 1 × 2 and MIMO2×4, respectively.
5. In the same scenario with 10 users, cell edge user spectral efficiency will be 0.07 bps/Hz/cell/user in DL 2 × 2, 0.09 in DL 4 × 2 and 0.12 in DL 4 × 4. In the UL, this cell edge user spectral efficiency must be 0.04 bps/Hz/cell/user with SIMO 1 × 2 and 0.07 with MIMO 2 × 4.
6. The mobility and coverage requirements are identical to LTE Release 8. There are only differences with indoor deployments that need additional care in LTE-Advanced.
7. In terms of spectrum flexibility, the LTE-Advanced system will support scalable bandwidth and spectrum aggregation with transmission bandwidths up to 100MHz in DL and UL.
8. LTE-Advanced must guarantee backward compatibility and interworking with LTE and with other

3GPP legacy systems.

3.3 LTE-Advanced Physical Layer

The physical layer implements OFDMA scheme on the downlink for high spectral efficiency, robustness against frequency-selectivity and multi-path interference. It supports flexible bandwidth deployment, facilitates frequency-domain scheduling and is well suited for MIMO techniques. In the uplink, LTE-Advanced uses SC-FDMA – OFDMA with DFT pre-coding. This implies a common structure of transmission resources compared to the downlink. The addition of the cyclic prefix supports frequency-domain equalization on the transmission. The transmission resource structure basic unit is the physical resource block (PRB). There are 12 subcarriers allocated for 0.5 milliseconds, in pairs, in time domain. The radio interface contains two frame structures to support both FDD and TDD [3GPP].

The following points present some of the design features of the downlink and uplink implementation.

1. Cell acquisition signaling synchronizes signals in sub-frames 0 and 5 of each 10 ms radio frame. The physical broadcast channel (PBCH) in sub-frame 0 of each radio frame carries the master information block (MIB), includes indication of system bandwidth and has robust design for cell-wide coverage. Also, the CRC indicates the number of transmitting antennas.
2. Downlink control signaling has a flexible design to avoid unnecessary overhead. The control region size is dynamically variable; length is indicated by the physical control format indicator channel in the first OFDM symbol of each sub-frame; it is designed to be robust, with 16 QPSK symbols transmitted with full frequency diversity. In the control region, the physical downlink control channel carries downlink control information messages (downlink resource assignments, uplink resource grants, and uplink powe control commands).
3. Downlink data transmission takes place through the physical downlink shared channel, which carries user data, broadcast system information and paging messages. The transmission resources are assign dynamically by the physical downlink shared channel. They are either localized, in which case suitable for frequency domain scheduling or distributed, suitable for maximizing frequency diversity.
4. In the uplink channel structure, data is transmitted on the physical uplink shared channel, placed in the center of the uplink bandwidth to minimize out-of-band emissions from wide-bandwidth data transmissions. It has the same channel coding and rate matching as the physical downlink shared channel. Also, 3 types of modulation are available: QPSK, 16QAM, and 64 QAM. When the channel is transmitted, any control signaling is multiplexed with data to maintain single carrier structure.
5. The physical uplink control channel carries control signaling in the absence of the physical uplink shared channel. It is usually present at the edges of the system bandwidth. The control channel hops from one side of the carrier to the other to maximize frequency diversity.
6. Uplink control signaling includes acknowledgements (ACK/NACK) for downlink shared channel transmissions, scheduling request and channel quality information (CQI – modulation index; PMI – preferred matrix for the downlink shared channel; RI – number of useful transmission layers for the downlink shared channel)

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4 LTE-Advanced Performance

The performance of systems such as LTE is already close to the Shannon limit. Thus, in order for LTE-Advanced to manage higher data rates, it must strive for better signal to noise ratios (SNR). Several

approaches have been discussed in [Parkvall09] that would improve SNR values. Wider-band transmission and spectrum sharing would meet the high-peak data rate requirement; however, in order to be backwards compatible, spectrum compatibility can be achieved through multiple LTE carrier components. Carrier aggregation is illustrated in Figure 1. Another implementation that would improve data rate is the use of multiple antennas. Technologies such as beam-forming and spatial multiplexing are already incorporated in LTE and are expected to be developed further in LTE-Advanced. Coordinated multi-point (CoMP) transmission is another method of improving system performance. In the downlink, it involves coordination of the transmissions from multiple transmission points depending on how much terminals are aware of transmissions originating from multiple points. Yet another solution would be the inclusion of relays and repeaters on the network node path; thus, the long distances among nodes are eliminated, allowing for higher data rates.

4.1 Assumptions

Several simple system tests have been carried out in [Parkvall09]; a CoMP system is simulated; some of the assumptions are listed in table 1 (attached), which are similar to 3GPP simulation case 1 in [3GPPd].

4.2 Numerical Results

According to [Parkvall09], "Fig. 2 and Fig. 3 show the resulting cell-edge and average active radio link bitrate (R) as a function of the served traffic per cell (T) for the downlink. It is seen that the CoMP system yields significant performance gains. As expected the gain is larger for the system with more coordinated cells. The loss due to using erroneous channel values at the transmitter is evident, but a majority of the gain remains. Fig. 4 and Fig. 5 show the resulting cell-edge and average active radio link bit rate (R) as a function of the served traffic per cell (T) for the uplink. It is seen that the CoMP system yields significant performance gains, and the gains are larger for the system with more coordinated cells. Recall that the transmitted signals in uplink CoMP are generated independently of the channel realizations; hence, from a coordination perspective there is no need to consider channel estimation errors at the transmitter for the uplink. These results are indeed very promising. Note however that several ideal assumption have been made that are challenging to solve, foremost including feedback of estimates of downlink channels (encoding and transmitting with low latency)."

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5 Conclusion

This paper has provided a high-level overview of the LTE-Advanced standard, from it's evolution as LTE, historical development and technical requirements needed to comply with IMT-Advanced goals, to an overview of the physical layer and performance capabilities.

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Acronyms

(in order of appearance)

LTE – Long Term Evolution

IMT – Internationale Mobile Telecommunications

3GPP - 3rd Generation Partnership Project

3/4 G – 3rd/4th generation

Gbps – gigabits per second

MHz – mega Hertz

Hz – Hertz

MIMO – multiple input multiple output

ITU – international telecommunication unit

RAN – regional area network

UTRA – UMTS Terrestrial Radio Access

OFDM – orthogonal frequency division multiplexing

SC-FDMA – single carrier frequency division multiple access

FFT – fast Fourier transform

IFFT – inverse fast Fourier transform

FDD – frequency division duplex

TDD – time division duplex

QPSK – quadrature phase-shift keying

16 QAM – 16 quadrature amplitude modulation

64 QAM – 64 quadrature amplitude modulation

WCDMA – wideband code division multiple access

DL – download

UL – upload

SIMO – single input multiple output

DFT – discrete Fourier transform

ACK/NACK – positive/negative acknowledgement

CoMP – coordinated multi-point (with regard to transmission)

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- Table 1