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Comparison Study on 3.9G and 4G Evolution

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Abstract. LTE-Advanced (4G) 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. LTE Advanced does meet most of the standards for 4G deployment, though it is often described as 3.9G or pre-4G. This paper presents a general comparison study between LTE (3.9G) and LTE-Advanced (4G) in terms of its capable of peak download data rates of 1 Gbps, wide transmission bandwidth, low C-plane latency, increased user throughput and spectrum flexibility.

Keywords: LTE, LTE-Advanced, Latency, Peak Data Rates, Spectrum Efficiency, Data Throughput.

1. Introduction

Mobile communication technologies are often divided into generations, with 1G being the analog mobile radio systems of the 1980s, 2G the first digital mobile systems, and 3G the first mobile systems is handling broadband data. The *Long-Term Evolution* (LTE) is often called “4G”, but many also claim that LTE release 10, also referred to as *LTE-Advanced*, is the true 4G evolution step, with the first release of LTE (release 8) then being labeled as “3.9G”. This continuing race of increasing sequence numbers of mobile system generations is in fact just a matter of labels. What is important is the actual system capabilities and how they have evolved. In this context, it must first be pointed out that LTE and LTE-Advanced is the same technology, with the “Advanced” label primarily being added to highlight the relation between LTE release 10.This does not make LTE-Advanced a different system than LTE and it is not in any way the final evolution step to be taken for LTE. Another important aspect is that the work on developing LTE and LTE-Advanced is performed as a continuing task within 3GPP, the same forum that developed the first 3G system (WCDMA/HSPA).

2. The 3G Evolution to 4G

The first release of WCDMA Radio Access developed in TSG RAN was called release 993 and contained all features needed to meet the IMT-2000 requirements as defined by the ITU.

This included circuit-switched voice and video services, and data services over both packet-switched and circuits watched bearers. The first major addition of radio access features to WCDMA was HSPA, which was added in release 5 with High Speed Downlink Packet Access (HSDPA) and release 6 with Enhanced Uplink. The 3G evolution continued in 2004, when a workshop was organized to initiate work on the 3GPP Long-Term Evolution (LTE) radio interface. The result of the LTE workshop was that a study item in 3GPP TSG RAN was created in December 2004. The first 6 months were spent on defining the requirements, or design targets, for LTE. These were documented in a 3GPP technical report [1] and approved in June 2005. Most notable are the requirements on high data rate at the cell edge and the importance of low delay, in addition to the normal capacity and peak data rate requirements. During the fall of 2005, 3GPP TSG RAN WG1 made extensive studies of different basic physical layer technologies and in December 2005 the TSG RAN plenary decided that the LTE radio access should be based on OFDM in the downlink and DFT-pre-coded OFDM in the uplink. TSG RAN and its working groups then worked on the LTE specifications and the specifications were approved in December 2007. Work has since then continued on LTE, with new features added in each release.

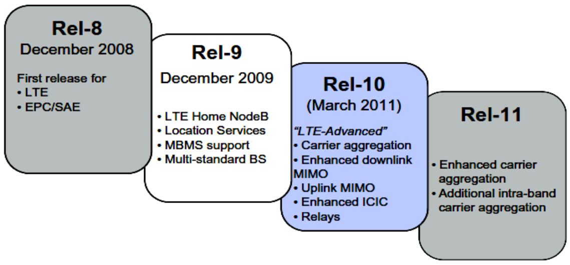

Fig. 1: The Release of 3GPP specifications for LTE

3GPP has completed the specification for Long Term Evolution as part of Release 8 as shown in Fig.1; the work on LTE began in 2004 and completed in 2009 and first deployment occurred in 2010.

In Release 8, Long Term Evolution (LTE) [2] was standardized by 3GPP as the successor of the Universal Mobile Telecommunication System (UMTS). The targets for downlink and uplink peak data rate requirements were set to 100 Mbit/s and 50 Mbit/s, respectively, when operating in a 20MHz spectrum allocation. First performance evaluations show that the throughput of the LTE physical layer and MIMO enhanced WCDMA is approximately the same. Basically 3GPP is addressing the requirements to satisfy the specification of IMT Advanced (International Mobile Telecommunications- Advanced) in LTE Advanced, LTE Advanced standards are defined in 3GPP Release 10 and expected to be finalized by 3GPP in 2011.

3. Long Term Evolution (LTE)

The goal of LTE (3.9G) is to provide a high-data-rate, low-latency and packet-optimized radio access technology supporting flexible bandwidth deployments. In parallel, new network architecture is designed with the goal to support packet-switched traffic with seamless mobility, quality of service and minimal latency [3].The air-interface related attributes of the LTE system are summarized in Table 1.

Table 1: LTE system attributes

Bandwidth		1.25–20 MHz
Duplexing		FDD, TDD, half-duplex FDD
Mobility		350 km/h
Multiple access	Downlink	OFDMA
	Uplink	SC-FDMA
MIMO	Downlink	2 × 2, 4 × 2, 4 × 4
	Uplink	1 × 2, 1 × 4
Peak data rate in 20 MHz	Downlink	173 and 326 Mb/s for 2 × 2 and 4 × 4 MIMO, respectively
	Uplink	86 Mb/s with 1 × 2 antenna configuration
Modulation		QPSK, 16-QAM and 64-QAM
Channel coding		Turbo code
Other techniques		Channel sensitive scheduling, link adaptation, power control, ICIC and hybrid ARQ

The system supports flexible bandwidths thanks to OFDMA and SC-FDMA access schemes. In addition to FDD (frequency division duplexing) and TDD (time division duplexing), half-duplex FDD is allowed to support low cost UEs. Unlike FDD, in half-duplex FDD operation.

A UE (User Equipment) is not required to transmit and receive at the same time. This avoids the need for a costly duplexer in the UE. The system is primarily optimized for low speeds up to 15 km/h. However, the system specifications allow mobility support in excess of 350 km/h with some performance degradation.

The uplink access is based on single carrier frequency division multiple access (SC-FDMA) that promises increased uplink coverage due to low peak-to-average power ratio (PAPR) relative to OFDMA.

The system supports downlink peak data rates of 326 Mb/s with 4 × 4 MIMO (multiple input multiple output) within 20MHz bandwidth. Since uplink MIMO is not employed in the first release of the LTE standard, the uplink peak data rates are limited to 86 Mb/s within 20MHz bandwidth. In addition to peak data rate improvements, the LTE system provides two to four times higher cell spectral efficiency relative to the Release 6 HSPA system. Similar improvements are observed in cell-edge throughput while maintaining same-site locations as deployed for HSPA. In terms of latency, the LTE radio-interface and network provides capabilities for less than 10 ms latency for the transmission of a packet from the network to the UE [3].

4. Long Term Evolution-Advanced (LTE-A)

3GPP LTE (4G) Release 10 ,LTE-Advanced, is developed so as to meet the diverse requirements of advanced applications that are set to become common place in the foreseeable future of the wireless services industry. It is expected to also drastically reduce the Capital Expenses (CAPEX) and Operational Expenses (OPEX) of future broadband wireless networks. Anticipating the invitation from the ITU, 3GPP already in March 2008 initiated a study item on LTE-Advanced, with the task of defining requirements and investigating the technology components of the evolution of LTE, an evolution including extending LTE to meet all the requirements of IMT-Advanced as defined by the ITU [4].

Furthermore, LTE-Advanced will be an evolution of LTE, thus making it possible for backward compatibility with LTE and it also designed to meet or even exceed all IMT-Advanced requirements including enhanced data rates of up to 1Gbps in the downlink and 500 Mbps in the uplink, increased capacity with the possibility of high data rates provided over a larger portion of the cell as well as low cost of deployment. The backward compatibility requirement for LTE-Advanced has a direct implication in the sense that, for an LTE terminal, a network with LTE-Advanced capabilities should appear as an LTE network. It is of critical importance to have such spectrum-compatible systems in order to achieve a smooth, low-cost transition to LTE-Advanced capabilities within the network.

The goals of LTE-Advanced and the manner in which these goals can be met are summarized below [5]:

- Flexible and faster network deployment achieved with the help of heterogeneous networks.
- Better coverage and improved spectral efficiency (cell edge and average) achieved through robust interference management.
- Greater flexibility with wideband deployments by employing wider bandwidth by carrier aggregation across bands.
- Ubiquitous & cost-effective broadband using higher peak user rate by higher order DL and UL MIMO.

5. LTE and LTE-Advanced System Performance Requirements

The importance development LTE and LTE-Advanced dependent to enhance the following:

5.1 Latency

Another very crucial factor in meeting IMT-Advanced requirements is network latency, which is defined as the round-trip time it takes data to traverse the network. Latency values have been dropping constantly since the era of GPRS and stood at an impressive 70 ms in HSDPA networks. However, with further improvements in HSUPA to about 50ms and with the use of 2ms Transmission Time Interval (TTI), it was just a matter of time before this value would be cut again. LTE-Advanced is targeting under 10ms also in the user plane and less than 50ms latency in the control plane.

In LTE Rel.8 the C-plane from Idle (with IP address allocated) to Connected in <100 ms, U-plane latency of less than 5 ms in unload condition (i.e single user with single data stream) for small IP packet and the LTE-A Rel.10 the C- plane from Idle (with IP address allocated) to Connected in <50 ms, U-plane latency reduced compared to Release 8 E-UTRA and E-UTRAN, specifically in situations where the UE does not have a valid scheduling assignment or the UE needs to synchronize and obtain a scheduling assignment [6].

5.2 Spectrum efficiency

The amount of bandwidth in a wireless network is ultimately determined by two factors: the spectral efficiency of the wireless interface and the amount of licensed spectrum a carrier owns. Spectral efficiency is measured as the amount of data (bits/s) that can be transmitted for every Hz of spectrum and the higher the number (bits/s/Hz) the better. As the wireless-data market grows, deploying wireless technologies with high spectral efficiency is becoming increasingly important. Increased spectral efficiency however is very costly as it would require greater complexity for both user terminals and BS equipment. This, therefore, means that operators and vendors must balance market needs against network and equipment costs if they are to last in the market. LTE-Advanced uses advanced interference management (AIM) techniques to provide robust performance, improve inter-cell fairness in heterogeneous networks and increase spectral efficiency but of even more importance is the multi-antenna techniques employed by both LTE-Advanced.

LTE-Advanced supports up to 8-stream transmissions with a resulting peak spectral efficiency of 30 and 15 bps/Hz in the downlink and uplink respectively [6]. Where the Peak spectrum efficiency for LTE Rel.8 DL is 16.3 b/s/Hz (4x4 MIMO) compare with LTE-Advanced Rel.10 is 30.6 b/s/Hz (8x8MIMO) and the UL for LTE Rel.8 is 8.4 b/s/Hz (2x2 MIMO), LTE-Advanced UL is 16.8 b/s/Hz (4x4 MIMO).

5.3 Data throughput

Data throughput is an important metric for quantifying network throughput performance. Unfortunately, the ways in which various organizations quote throughput statistics vary tremendously which often leads to misleading claims. To address the issue of improved data throughput, LTE-Advanced is implementing relay technologies which have great application potential. The performance of relay transmissions however, is greatly affected by the collaborative strategy, which includes the selection of relay types and relay partners. Target for LTE-Advanced was set considering gain of 1.4 to 1.6 from Release 8 LTE performance [6].

5.4 Larger bandwidth

LTE-A support of asymmetrical bandwidths and larger bandwidth (maximum of 100MHz) as Fig.2, In LTE (release 8) can support variable bandwidths in the range between 1.4 and 20MHz, the bandwidth could have different sizes but had to be the same in the downlink and in the uplink. In LTE-Advanced (Release 10) bandwidths can be different because due to actual demand in mobile networks, the traffic from the station to the user is bigger than the one from the user to the station. And they can be as asymmetric as they want within the limit of the 100 MHz LTE-Advanced provides. The sum of both bandwidths (downlink + uplink) cannot exceed 100 MHz. Carrier aggregation to achieve wider bandwidth is a key factor as well as the support of spectrum aggregation, to achieve higher bandwidth transmissions. Fig. 2 shows the B.W for LTE and LTE-Advanced.

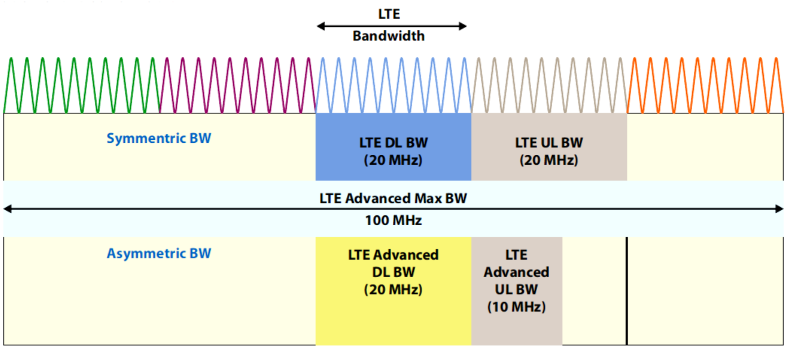

Fig. 2: Shows the B.W for LTE and LTE-Advanced.

5.5 Peak data rates

LTE has been developed in a process where design targets for performance parameters play an important role. One target is for the peak data rate over the radio interface. The original design targets for the first release of LTE are documented in 3GPP TR 25.913 [7]. The target capability when operating in a 20 MHz spectrum allocation is a peak data rate of 100 Mbit/s in the downlink and 50 Mbit/s in the uplink.

The numbers assume two receive antennas in the terminal for the downlink capability and one transmit antenna for the uplink capability. These target numbers are exceeded by a good margin by the peak data rate capability of the specified LTE standard. LTE release 8 supports peak data rates of 300 Mbit/s in the downlink and 75 Mbit/s in the uplink by using spatial multiplexing of four layers (4 x 4 MIMO) in the downlink and 64QAM in both downlink and uplink. With the assumptions in the design targets that is, spatial multiplexing of two layers the downlink peak data rate is 150 Mbit/s, which is still significantly higher than the target. The design targets for LTE release 10 ("LTE-Advanced") are documented in 3GPP TR 36.913 [7], based on the targets set by ITU-R [8]. There is no absolute peak data rate target expressed for LTE release 10; it is instead expressed relative to the channel bandwidth as a peak spectral efficiency, with targets of 15 bit/s/Hz for downlink and 6.75 bit/s/MHz for uplink [8]. LTE release 10 exceeds those numbers by a good margin. The assumptions for deriving the peak spectral efficiency numbers is a deployment with 20 MHz channel bandwidth, 8 x 8 MIMO in the downlink, and 4 x 4 MIMO in the uplink. Spectrum allocation is a peak data rate LTE-A of 1 Gbit/s in the downlink and 500 Mbit/s in the uplink.

6. Summary and Discussion

3.9G (LTE)	4G (LTE-Advanced)
LTE (3.9G) is not backward compatible with any 3G networks. LTE is part of 3GPP Release 8.	LTE-Advanced (4G) is backward compatible with LTE. LTE-Advanced is part of 3GPP Release 10.
LTE will also forward and backward compatible with LTE- Advanced.	LTE-Advanced will be forward and backward compatible with LTE.
3GPP has completed the specification for Long Term Evolution as part of Release 8. The work on LTE began in 2004 and completed in 2009 and first deployment occurred in 2010.	Basically 3GPP is addressing the requirements to satisfy the specification of IMT Advanced (International Mobile Telecommunications- Advanced) in LTE-Advanced; LTE-Advanced expected to be finalized by 3GPP in 2011.
LTE is supposed to offer 326 Mbps with 4×4 MIMO and 172 Mbps with 2×2 MIMO in 20 MHz spectrum.	LTE-Advanced offers speed of 40 times faster than 3G commercial networks. Using antenna configurations of 8 x 8 in DL and 4 x 4 in the UL.
Coverage Full performance up to 5 km.	a) Same as LTE requirement. b) Should be optimized or deployment in local areas/micro cell environments.
The major advantage in LTE is high throughput with low latency.	LTE-Advanced offers All-IP, High Speed, Low Latency in mobile network which enhances the experience of mobile triple play services and it is 3 times higher average user throughput than LTE.
Mobility: LTE - Support mobility across the cellular network for various mobile speeds up to 350km/h (or perhaps even up to 500km/h depending on the frequency band).	Mobility: LTE-Advanced Same as that in LTE, System performance shall be enhanced for 0 to 10km/h. LTE Advanced would operate in spectrum allocations of different sizes including wider spectrum allocations than those of Release 8 to achieve higher performance.
New cellular standard -Enhanced UTRA (E-UTRA) **E**volved **U**niversal **T**errestrial **R**adio **A**ccess.	LTE-Advanced will be standardized in the 3GPP specification Release 10 (LTE-A) and LTE-Advanced was accepted by the International Telecommunication Union Radiocommunication Sector (ITU-R) as a technology compliant with the requirements of IMT-Advanced.
LTE devices can work in LTE Advanced.	LTE-Advanced devices can operate in LTE and vice versa.
It is suitability for deployment in scalable bandwidths ranging from 1.25MHz to 20 MHz.	Transmission bandwidth BW about 100 MHz in DL and 40 MHz in UL.
Peak data rate: LTE - DL: 100 Mbps, UL: 50 Mbps.	Peak data rate: LTE Advanced - DL: 1 Gbps, UL: 500 Mbps.
Latency: LTE - C-plane from Idle (with IP address allocated) to Connected in <100 ms, U-plane latency of less than 5 ms in unload condition (i.e single user with single data	Latency: LTE Advanced - C- plane from Idle (with IP address allocated) to Connected in <50 ms, U-plane latency reduced compared to Release 8 E-UTRA and E-UTRAN,

stream) for small IP packet.	specifically in situations where the UE does not have a valid scheduling assignment or the UE needs to synchronize and obtain a scheduling assignment.
Peak spectrum efficiency: LTE - DL 3 to 4 times Release 6 HSDPA, UL - 2 to 3 times Release 6 Enhanced Uplink.	Peak spectrum efficiency: LTE Advanced - DL 30 bps/Hz and UL 15 bps/Hz.
plane capacity: LTE - At least 200 users per cell should be supported in the active state for spectrum allocations up to 5 MHz.	plane capacity: LTE Advanced - At least 300 active users without DRX (Discontinuous Reception) in a 5 MHz Bandwidth.
Scalable Band Widths: 1.3, 3, 5, 10 and 20 MHz. Connection setup delay <100 ms.	Scalable Band Widths: Up to 20-100 MHz Connection setup delay <50 ms.
Capacity 200 active users per cell 5 MHz.	3 times higher than that in LTE.

7. Acknowledgment

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8. Conclusion

In this paper the main targets for this evolution LTE and LTE Advanced are increased data rates, improved spectrum efficiency, improved coverage, reduced latency and packet-optimized system that support multiple Radio Access Technologies.

After comparison the LTE-Advanced (4G) is better than LTE (3.9G) in some specifications such as: LTE-Advanced 4G have Data rates up to 1Gbps in stationary scenarios, Coverage enhancements for high frequency bands, LTE-Advanced will be a smooth evolution of LTE, Numerology and access technologies will be the same, Bandwidth up to 100MHz supported, Contiguous and non-contiguous carrier aggregation, New technologies are being proposed, Enhanced MIMO, cooperative transmission, relaying etc.

LTE-Advanced is a very flexible and advanced system, further enhancements to exploit spectrum availability and advanced multi-antenna techniques.

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