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Evolution of LTE and Related Technologies towards IMT-Advanced

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Abstract— The Long Term Evolution (LTE) is an emerging technology, which is standardized by the Third Generation Partnership Project (3GPP) and evolving to meet the International Mobile Telecommunication Advanced (IMT-Advanced) requirements named as LTE-Advanced. The main goal of LTE is to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments. The network architecture of LTE has been designed with the goal to support packet-switched traffic with seamless mobility and great quality of service.
In this paper, we provide in-depth, the evolution and the major basic features of LTE to LTE-Advanced. Finally, we summarize the LTE-Advanced features in tabular format and show how LTE can fulfil the IMT-Advanced requirements.

Keywords— IMT-Advanced, LTE, LTE-Advanced, LTE Features, LTE-A Vs IMT-A.

I. INTRODUCTION

The First Cellular based Mobile Telecommunication system was developed by the north European countries named as Nordisk MobilTelefoni (NMT) which was first commercially launched in Japan in 1979. Another system called Advanced Mobile Phone System (AMPS) developed by United States of America (USA) in 1983 is also called cellular based system [14], [15]. These two systems are referred to as 1st generation (1G) analogy mobile communication systems. The digital cellular standard was introduced in the 2nd generation (2G) mobile communication system. The Global System for Mobile Communication (GSM) founded in 1987 based on Time-Division Multiple Access (TDMA) and Interim Standard 95 (IS-95) based on Code Division Multiple Access technology are referred to as 2G systems. The development of 3rd generation (3G) cellular standard was initiated by the groups of telecommunication associations. In 1998, the third generation partnership project (3GPP) started their work to develop 3G cellular standard based on GSM network and 3GPP2 continued to evolve the IS-95 network to 3G standard. These two systems are based on CDMA access technology and the 3G requirements were defined as International Mobile Telecommunication-2000 (IMT-2000) issued by the International Telecommunication Union (ITU-R). The 3G standard that was released by 3GPP is referred to as release 99 or UMTS (Universal Mobile Telecommunication System) and the standard released by 3GPP2 is referred to as CDMA-2000 [1].The International Telecommunication Union (ITU-R) announced the fourth generation (4G) mobile communication requirements in 2008 named as the International Mobile Telecommunications-Advanced (IMT-Advanced). After this announcement, the two projects 3GPP and 3GPP2 started their work to meet the 4G IMT-Advanced requirements. 3GPP's 4G project towards IMT-Advanced was named as LTE (Long Term Evolution) and its further enhancement is LTE-Advanced. 3GPP2 started their 4G project named as UMB (Ultra Mobile Broadband) but stopped its development in November 2008 and accepted LTE instead [9].

This paper focuses on IMT-Advanced technologies of the fourth generation (4G) mobile communication. The rest part of this paper is organized as follows: Section II starts with the background history of LTE and related technologies, section III provides the evolution mostly focusing on LTE and describes how LTE has been evolving in order to meet and exceed the IMT-Advanced requirements. A brief description of IMT-Advanced requirements for 4G standard are summarized in section IV. We make a comparative study between LTE-Advanced (Enhanced release of LTE) and IMT-Advanced to figure out how LTE-Advanced can fulfil and sometimes exceed the IMT-Advanced requirements. Finally, we conclude our discussion in section VI.

II. BACKGROUND HISTORY OF LTE AND RELATED TECHNOLOGIES

The 3rd Generation Partnership Project (3GPP) unites six telecommunications standard development organizations like ARIB (The Association of Radio Industries and Businesses, Japan), ATIS (The Alliance for Telecommunications Industry Solutions, USA), CCSA (China Communications Standards Association), ETSI (The European Telecommunications Standards Institute), TDSI (Telecommunications Standards Development Society, India), TTA (Telecommunications Technology Association, Korea) and TTC (Telecommunication Technology Committee, Japan) to work together to develop a new cellular standard called 3G. They used CDMA based radio access technology for 3G rather than FDD-TDMA. In order to facilitate "Global Roaming" between US and European markets, 3GPP was formed in 1998 and in 2000, 3GPP released its first version of the standard named as UMTS (Universal Mobile Telecommunication System) or release 99 where the radio access technology is based on Wideband-CDMA (WCDMA). Further developments of 3GPP up to Release 7 (HSPA+) were based on CDMA access technology. When CDMA based access technology network exhausted its limit to provide the increasing demand of higher data rate, then 3GPP decided to develop a new standard based on a new access technology. The 3GPP team used Orthogonal Frequency Division Multiple Access (OFDMA) technology instead of CDMA and named the new standard as long term evolution (LTE) [1]. For the details of LTE, interested readers are referred to [10].

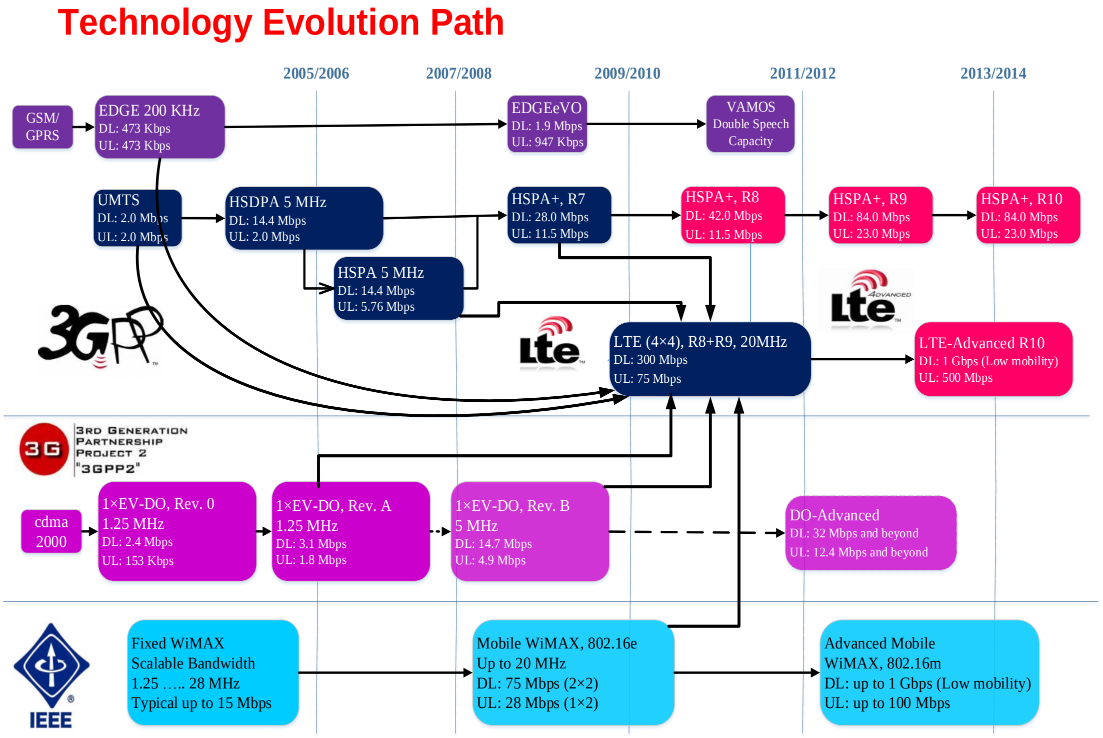

Fig. 1: Technology evolution path of different mobile networks

Figure 1 shows three different projects namely the 3GPP, 3GPP2 & IEEE which are working on 4G in order to meet the IMT-Advanced requirements. The 3GPP2 project started to work towards 4G but stopped the developments in 2008 and accepted LTE. The remaining two projects have already declared their 4G products as LTE-Advanced by 3GPP and as IEEE 802.16m by IEEE. These two technologies have been accepted as true 4G system by ITU-R in October, 2010. LTE can connect all other earlier mobile technologies in a single point which means the handover among different technologies are supported.

International Mobile Telecommunication-Advanced (IMT-Advanced) standard is defined by the International Telecommunication Union (ITU) that standardized to provide the need of very high data transmission rates (both for fixed and mobile stations) and seamless mobility among the heterogeneous networks. After the announcement of IMT-Advanced requirements for 4G standard issued by the ITU-R in 2008, 3GPP started their work to meet the IMT-Advanced requirements. The LTE is the emerging technology to meet the above requirements. LTE is a mobile broadband system defined by the Third Generation Partnership Project (3GPP). LTE is the evolution of GSM/UMTS standard of 3GPP. The main goal of LTE is to provide high speed data rates and seamless mobility among the heterogeneous networks to the mobile users. The number of mobile users as well as the requirements for high speed data rates are increasing day by day rapidly. This rapid growth demands higher data rates with mobility services. How these services then can be achieved by LTE? This paper provides an answer to this question. The next section provide a brief overview of basic features of LTE from its first release to LTE-Advanced. The 3GPP LTE standard from Release 10 and beyond are called LTE-Advanced which is the further improvements of LTE. LTE-Advanced successfully meet all the IMT-Advanced requirements and sometime exceeds beyond the requirements.

ITU-R decided in October 2010 that, the submitted LTE-Advanced system proposal successfully met all the requirements for the first release of IMT-Advanced, qualifying it as the first true fourth-generation (4G) systems [2]. The LTE-Advanced is already going through the trial phase by different countries and even in commercial operation launched in the year 2014.

III. EVOLUTION OF LTE TO LTE-ADVANCED

The development of LTE began during the period of HSPA+ (High Speed Packet Access plus) release of 3GPP in December 2004 [3]. The first release of LTE is called the release 8 of 3GPP which was introduced in December 2008. The release 9 of 3GPP finalized in December 2009 is the second release of LTE. After that, LTE-Advanced came into the market in June 2011 by the 3GPP as release 10. The release 10 and beyond by the 3GPP are called LTE-Advanced [4]. The brief description of LTE evolutions up to LTE-Advanced are summarized below:

A. LTE Release 8

The Release 8 of 3GPP is referred to as the first LTE standard. The deployment layout of first LTE release is mainly macro/microcell based layout. It can provide high peak data rates than earlier HSPA+, the system capacity and the area coverage has been improved. Other major features that improved in LTE release 8 are low latency, reduced operating costs, multi-antenna support, flexible bandwidth operation and seamless integration with existing systems [5]. In LTE: The OFDMA (Orthogonal Frequency Division Multiple Access) based radio access technology network is used on the downlink and SC-FDMA (Single carrier-Frequency Division Multiple Access) on the uplink. SC-FDMA is similar to OFDMA. It has an extra DFT processing step before OFDMA and is also referred to as DFTS-OFDMA [5-7]. One of the main properties of LTE radio access technology is Spectrum flexibility. LTE supports both FDD (Frequency Division Duplex) and TDD (Time Division Duplex). FDD is accomplished through 3G-WCDMA and TDD through TD-SCDMA as well as TD-CDMA. LTE release-8 has introduced Multi-Antenna transmission as an integral part of it. It also supports diversity with transmit diversity and downlink-receive diversity. Beam forming and spatial multiplexing (including both of single-user Multiple-Input Multiple-Output [SU-MIMO] and multi-user MIMO [MU-MIMO]) which supports up to four antennas is also included in this release.

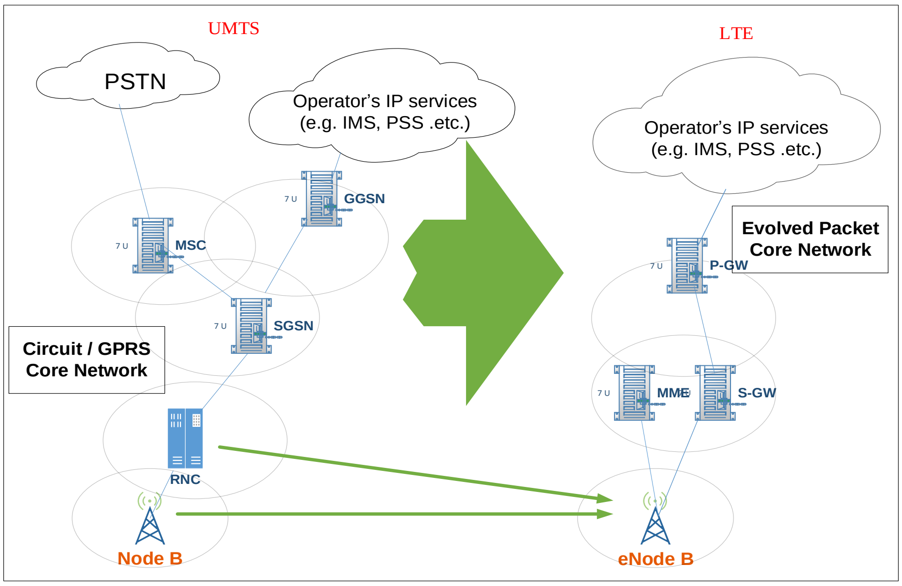

Fig. 2: GSM Access Network Vs LTE Access Network

Figure 2 above explains how LTE access network evolved from earlier GSM network architecture of UMTS. Node B and RNC are combined as eNode B (Evolve Node B) in the LTE network. Node B is controlled by the RNC that bring extra burden to the network and it added an extra delay to the network response time. But in LTE network it simplifies as eNode B which removes the extra delays of network response time. In UMTS network structure, the Circuit core network and the Packet core network are handled by different nodes of MSC and GSN respectively. But in LTE network architecture, we can see only packet based core network which is managed by different nodes like MME (Mobile Management Entity), S-GW (Serving Gateway) and P-GW (PDN Gateway).

LTE uses OFDMA radio access technology and provides orthogonality between multiple users both for uplink and downlink channel, so there is no interference within the same cell but there is inter-cell interference. **Power control** and **inter-cell interference coordination** is also an essential property of LTE [6, 7]. From the figure below, we can see the radio access network evolution from GSM to LTE network. The earlier GSM used FDD-TDMA radio access technology and then GSM evolved to the 3G network named as UMTS where CDMA based radio access technology is used. Due to the increasing demand of higher data transmission rates CDMA reached its limit and was unable to handle the increasing demand.

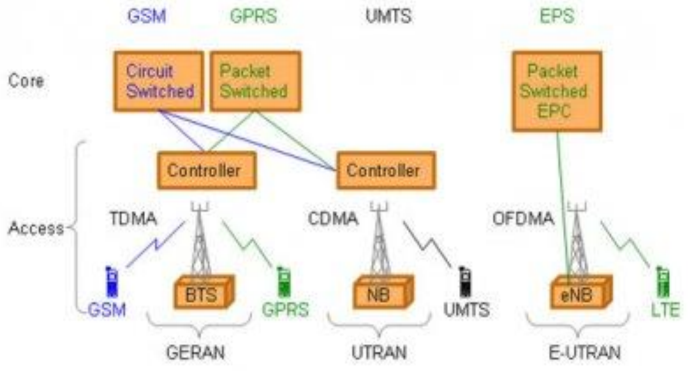

Fig. 3: Radio Access Network solution from GSM to LTE [4]

Figure 4 shows the Protocol structure of LTE which consists of three important layers. A very good article on LTE-link layer design is described in [11]. Retransmission handling and multiplexing of data flows are the functions of radio link control (RLC) and medium access control (MAC) layers respectively. In the physical (PHY) layer the transmitting data performs three processing functions before transmission: data is turbo coded and performs modulation using QPSK or M-QAM and finally followed by OFDM modulation [6].

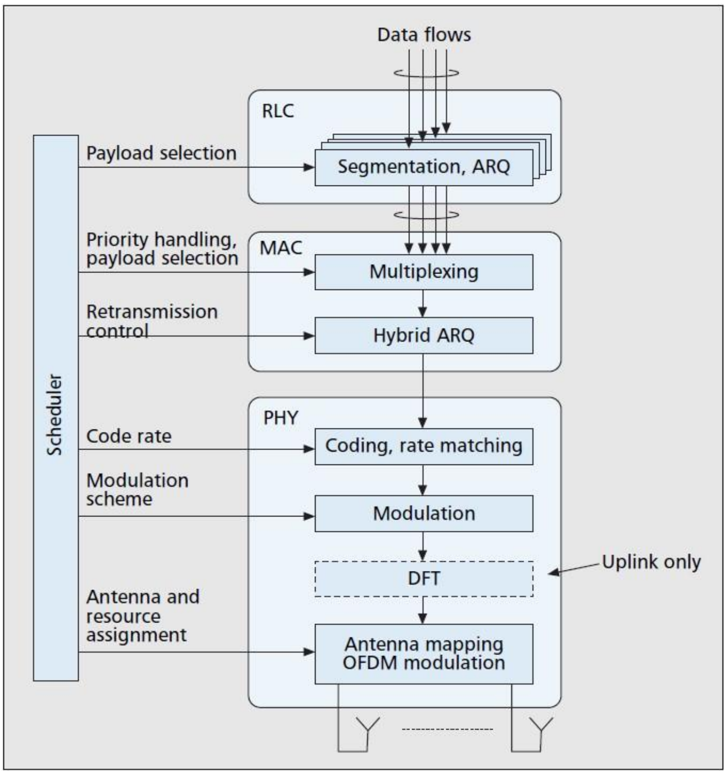

Fig. 4: LTE Protocol Structure (simplified) [6]

The LTE release-8 can provide up to 300Mbps downlink peak rate and 75Mbps uplink with a very small delay of radio-network (less than 5 ms) [7] as well as support mobility of up to 500Km/h.

B. LTE Release 9

LTE Release 9 has a minor enhancement than LTE Release 8. The additional enhancements added in this release are broadcast/multicast services, positioning services, and enhanced emergency-call functionality. Improvements in beam-forming of LTE can support dual-layer for downlink in release 9 [7].

In fact, the LTE release 9 is the complete release of LTE which was not completed in release 8. LTE Release 9 provides some smaller optimizations or improvements for a set of features. These features include:

- Multimedia Broadcast Multicast Services (MBMS) for LTE
- LTE MIMO: dual-layer beamforming
- LTE positioning
- PWS (Public Warning System)
- RF requirements for multi-carrier and multi-RAT base stations
- Home eNodeB specification (femto-cell)
- Self-Organizing Networks (SON).

Release 9 was finalized in the end of December 2009. The first commercial LTE was deployed in Sweden and Norway in 14 December, 2009. This deployment was the Release 9 of LTE, which provided interoperability between WiMAX (IEEE 802.16) and converged together the WCDMA of 3GPP and CDMA-2000 of 3GPP2.

C. LTE Release 10

LTE Release 10, was finalized at the end of 2010 in which further improvements were added compared to release 8/9 in terms of performance and capabilities. LTE Release 10 and beyond are called LTE-Advanced which meet all the requirements of IMT-Advanced. So LTE-Advanced is a 4G mobile communication system which includes some additional features than previous releases. These features includes:

- Carrier aggregation
- Advanced MIMO techniques
- Wireless relaying
- Enhanced Inter-cell interference coordination (eICIC)
- Coordinated multipoint (CoMP) transmission/reception.

In carrier aggregation, multiple carrier components are aggregated to provide support for high transmission bandwidth. LTE-Advanced can support carrier aggregation of up to 100 MHz. Advanced MIMO techniques can support 30bps/Hz in the downlink which requires 8x8 antenna configuration with MIMO spatial multiplexing and 16bps/Hz in the uplink which requires 4x4 antenna configuration. Wireless relaying provides cell coverage extension and improved cell edge performance. The home-eNB (HeNB) can be a relay node (RN). The deployment of heterogeneous LTE network demands enhanced inter-cell interference coordination which is an important feature of LTE-A. When an UE is in cell edge area then it receives signal from another base station which is as interference for the UE. CoMP is a solution to increase the system throughput in cell edge area in the presence of inter-cell interference [1].

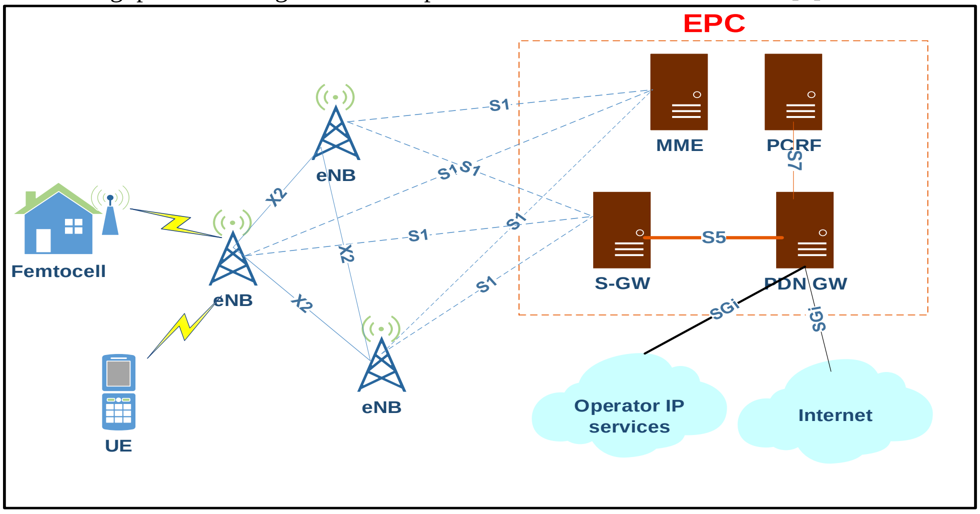

Fig. 5: LTE-Advanced Network Architecture.

The network architecture of LTE-Advanced is illustrated in figure 5. The LTE architecture shows the different components of LTE-Advanced network. All of the eNBs (Evolved NodeB) are connected to the S-GW (Serving Gateway) and MME (Mobility Management Entity) of EPC (Evolved Packet Core). eNB is the combination of UMTS (3G) NB and RNC (Radio Network Control). S-GW is responsible for routing, forwarding voice and data packets between UE and PDN (Packet Data Network). The handover between eNBs are also the jurisdiction part of S-GW. MME is responsible for control signalling, selecting appropriate GW during initial registration process. It's a vital part in handover signalling between LTE and 2G/3G networks. PDN-GW provides connectivity to the UEs with external packet data networks. The policy and charging rules are managed by the PCRF [1].

From Release-10, the LTE is called LTE-Advanced which has a major enhancements than other two releases. Many other enhancements are also introduced in further releases [12]. A comparison study among LTE releases (Release 8 to 10) by considering what enhancements have been done in the newer versions is summarized in table 1 below:

Table I enhancements in lte releases

I. Enhancements in LTE releases		
Release-8	**Release-9**	**Release-10 (LTE-A)**
•Spectrum flexibility •Multi antenna transmission •ICIC	•Spectrum flexibility •Multi antenna transmission •ICIC •LTE positioning •broadcast/multicast services (MBMS) •Home eNodeB specification (femto-cell) •LTE MIMO: dual-layer beamforming,	•Carrier aggregation •Advanced MIMO techniques •Wireless relaying •eICIC •CoMP transmission/reception •Relay node [HeNB] (femto-cell)

There are also further developments of LTE up to Release 13. We have only focused up to the starting of LTE-Advanced (R10) which meets the requirements of IMT-Advanced. By the end of the year 2014 LTE-Advanced has been launched in commercial operation in many countries. LTE-Advanced can support peak data rate 3Gbps for downlink and 1.5Gbps for uplink [4].

D. LTE Release 11 to 13

The development of LTE release 11 freezed in March 2013 and then 3GPP released the stable protocol. The major features of LTE release 11 are Advanced IP Interconnection of Services, System Improvements to Machine-Type Communications, QoS Control Based on Subscriber Spending Limits, Optimized Service Charging and Allocation of Resources in IMS whilst Roaming, Non Voice Emergency Services, Support for 3GPP Voice Interworking with Enterprise IP-PBX, Anonymous Call Rejection in the CS domain, Network-provided Location information for IMS (NETLOC) and so on [4]. LTE release 12 is not yet stabilized by 3GPP but planning to freeze and release the stable version of the protocol in March 2015. As well as the freeze plan for release 13 is in March 2016.

IV. REQUIREMENTS OF IMT-ADVANCED

IMT-Advanced requirements are the requirements which define the 4G standard of mobile communications. The ITU-R impose these requirements for any standard to be a fourth generation mobile communication system. The major requirements are including IP-based core network, high peak data rate (both for mobile and fixed users), low latency during session initiation and handover, high-speed mobility support, improved performance on the edge of a cell, VoIP support, seamless connectivity between terminal and base station among mobile networks, worldwide roaming capability, capability of interworking with other radio access systems (backward compatibility) and so on [8]. For the details of requirements and evaluation criteria of IMT-Advanced, interested readers are referred to [13].

V. IMT-ADVANCED VS LTE-ADVANCED

It is already mentioned that the LTE-Advanced system successfully fulfils and sometimes exceeds the IMT-Advanced requirements. So the LTE-Advanced system has been accepted as a true fourth generation (4G) system by the ITU-R in October 2010. The 3GPP team started their work in March 2008 [7] to develop LTE-Advanced to meet the IMT-Advanced requirements set by the ITU [8]. The comparison study between the features of LTE-Advanced and the requirements of IMT-Advanced are summarized in Table II below.

In order to deliver the requirements for high data rates and spectral efficiency, we have shown how the LTE physical layer implements a number of technologies such as OFDMA with MIMO (Both Single user and Multi user) which allows the downlink to provide as high as 100 Mbps in link throughput while SC-FDMA on the uplink reduces design complexity for the user terminals. SC-FDMA on the uplink is the DFT (Discrete Fourier Transform) precoded FDMA which has a smaller PAPR (Peak to average power ratio) than conventional FDMA.

Table II A study comparison of IMT-Advanced and LTE-Advanced

Performance Metrics	**IMT-Advanced Requirements**	**LTE-Advanced**
Core Network	IP based	IP based
Chanel Access Technology	OFDMA based	OFDMA/SC-FDMA
Duplex method	FDD, TDD	FDD, TDD
Peak data rate	DL 1Gbps, UL 1Gbps	DL 3Gbps, UL 1.5Gbps
Peak spectral efficiency	DL 15 bps/Hz, UL 6.75 bps/Hz	DL 30 bps/Hz, UL 16 bps/Hz
Bandwidth	Scalable, minimum 40 MHz	Scalable, up to total 100 MHz
Latency	User plane : 10 ms (max) Control plane: 100 ms (max)	User plane : 10 ms (max) Control plane: 50 ms (max)
Handover interrupt time	Intra-frequency: 27.5 ms Inter-frequency: 40 ms & 60 ms	Maximum 15.6 ms in TDD case.
Mobility support	Maximum 350 Km/h	Maximum 500 Km/h
Seamless mobility	Among different mobile networks	Support seamless mobility
VoIP capacity	50 users/sector/MHz	Support and exceed

VI. CONCLUSION

This paper has provided a high level overview of LTE features from release-8 to release-13. The comparison study in the earlier section of this paper shows that, the release 10 of 3GPP already supports and exceeds all the IMT-Advanced requirements and accepted as a true 4G system. There are further enhanced releases of LTE also available which are release 11 to 13. Currently 3GPP is working on release-13 which can be able to perform as a more improved system than previous releases (i.e., Release-10, 11 and 12).

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