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Sophistication Techniques of Fourth Generations in Neoteric Mobile LTE and LTE-Advanced

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ABSTRACT

Long Term Evolution (LTE-Advanced) is a preliminary mobile communication standard formally submitted as a candidate for 4G systems to the ITU-T. LTE-A is being standardized by the 3rd Generation Partnership Project (3GPP) as a major enhancement of the 3GPP Long Term Evolution (LTE-Release 8) standard, which proved to be sufficient to satisfy market's demand. The 3GPP group has been working on different aspects to improve LTE performance, where the purpose of the framework provided by LTE-Advanced, includes higher order MIMO, carrier aggregation (carriers with multiple components), peak data rate, and mobility. This paper presents a study on LTE evolution toward LTE-Advanced in terms of LTE enabling technologies (Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO)), and also focuses on LTE-Advanced technologies MIMO enhancements for LTE-Advanced, Coordinated Multi Point transmission (CoMP).

KEYWORDS

LTE; LTE-Advanced; MIMO; OFDMA; SCFDMA; CoMP.

1 INTRODUCTION

The specifications for LTE are produced by the Third Generation Partnership Project [1], in the same way as the specifications for UMTS and GSM. They are organized into releases, where each of which contains a stable and clearly defined set of features. The use of releases allows equipment manufacturers to build devices using some or all of the features of earlier releases, while 3GPP continues to add new features to the system in a later release. Within each release, the specifications progress through a number of different versions. New functionality can be added to successive versions until the date when the release is frozen, after which the only changes involve refinement of the technical details, corrections and clarifications [2].

Table 1 lists the releases that 3GPP have used since the introduction of UMTS, together with the most important features of each release. Note that the numbering scheme was changed after Release 99, so that later releases are numbered from 4 through to 11 (LTE-A).

Table 1
3GPP specification release for LTE and LTE-A

Release	Date frozen	New features
R99	March 2000	WCDMA air interface
R4	March 2001	TD-SCDMA air interface
R5	June 2002	HSDPA, IP multimedia subsystem
R6	March 2005	HSUPA
R7	December 2007	Enhancements to HSPA
R8	December 2008	LTE, SAE
R9	December 2009	Enhancements to LTE and SAE
R10	March 2011	LTE-Advanced
R11	September 2012	Enhancements to LTE-Advanced

Section 2 of this paper discusses the system requirements for LTE and LTE-Advanced, while section 3 describes the standards of long term evolution. Key enabling technologies and feature of LTE are described in section 4 with the uplink and downlink system model and MIMO. In section 5, the standards of long term evolution Advanced are reviewed appended by the characteristics of carrier aggregation, peak data rate, mobility and OFDMA. In section 6 the LTE-Advanced technologies are considered which include MIMO enhancements for LTE-Advanced with both types' of uplink and downlink MIMO transmission, the coordinated multi-point transmission. Section 7 contains the summary and discussion of the main points for this paper which would be useful for reader to understand the current development for performance of release 8 and release 10 in wireless communications. Finally, section 8 concludes some general observations and recommendations for this paper.

2 SYSTEM REQUIREMENTS FOR LTE AND LTE-ADVANCED

Table 2 gives the system requirements for the Rel. 8 LTE. The Rel. 8 LTE supports scalable multiple transmission bandwidths including 1.4, 3, 5, 10, 15, and 20MHz. One of the most distinctive features is the support for only the packet-switching (PS) mode. Hence, all traffic flows including real-time service with a rigid delay requirement such as voice services is provided in the PS domain in a unified manner. The target peak data rate is 100 Mbps in the downlink and 50 Mbps in the uplink. The target values for the average or cell edge user throughput and spectrum efficiency are specified as relative improvements from those of High-Speed Downlink Packet Access (HSDPA) or High-Speed Uplink Packet Access (HSUPA) in the downlink and uplink, respectively. Here, the average cell spectral efficiency corresponds to capacity, and the cell-edge user throughput is defined as the 5% value in the cumulative distribution function (CDF) of the user throughput. Both are very important requirements from the viewpoint of practical system performance in cellular environments. In particular, improvement in the cell-edge user throughput is requested to mitigate the unfair achievable performance between the vicinity of the cell site and cell edge. After extensive discussions in the 3GPP meetings, it was verified that the requirements and targets for the Rel. 8 LTE were achieved by the specified radio interface using the relevant techniques.

Table 2
Major System Requirement for Rel.8 LTE [3]

Bandwidth	Support of scalable bandwidths (1.4, 3, 5, 10, 15, and 20 MHz)	
Peak data rate	DL	100 Mbps
	UL	50 Mbps
Spectrum efficiency (vs. Rel. 6 HSDPA/HSUPA)	DL	3 – 4 times
	UL	2 – 3 times
User throughput (vs. Rel. 6 HSDPA/HSUPA)	DL	3 – 4 times (average) 2 – 3 times (cell edge)
	UL	2 – 3 times (average) 2 – 3 times (cell edge)

The requirements for LTE-Advanced are specified in [3]. The following general requirements for LTE-Advanced were agreed upon. First, LTE-Advanced will be an evolution of Rel. 8 LTE. Hence, distinctive performance gains from Rel. 8 LTE are requested. Moreover, LTE-Advanced will satisfy all the relevant requirements for Rel. 8 LTE. Second, full backward compatibility with Rel. 8 LTE is requested in LTE-Advanced. Thus, a set of user equipment (UE) for LTE-Advanced must be able to access Rel. 8 LTE networks, and LTE-Advanced networks must be able to support Rel. 8 LTE UEs. Third, LTE-Advanced shall meet or exceed the IMT-Advanced requirements within the ITU-R time plan.

In Table 3, the requirements and target values for LTE-Advanced and IMT-Advanced are listed with those achieved in the Rel. 8 LTE. The summary of the major issues which depend on MIMO channel transmissions is highlighted, with respect to the peak data rate, the CL refers to Recommendation ITU-R M.1645, which specifies that the target peak data rate for IMT-Advanced should be higher than 1 Gbps in nomadic environments. Based on the description in the CL, the target peak data rate for the downlink was set to 1 Gbps for LTE-Advanced. Meanwhile, the target peak data rate for the uplink was set to 500 Mbps. The target values for the peak frequency efficiency are 2 and 4 fold those achieved in the Rel. 8 LTE, i.e., 30 and 15 bps/Hz in the downlink and uplink, respectively. It is noted, however, that this requirement is not mandatory and is to be achieved by a combination of base stations (BSs) and high-class UEs with a larger number of antennas. In LTE-Advanced, 1.4 to 1.6 folds improvements for the capacity and cell-edge user throughput are expected from Rel. 8 LTE for each antenna configuration.

Table 3
System Performance Requirements for LTE-A compared to those achieved in Rel.8 LTE [3]

	DL/UL	Antenna configuration	Rel. 8 LTE achievement	LTE-Advanced	IMT-Advanced
Peak data rate	DL	–	300 Mbps	1 Gbps	1 Gbps
	UL	–	75 Mbps	500 Mbps	
Peak spectrum efficiency [bps/Hz]	DL	–	15	30	15
	UL	–	3.75	15	6.75
Capacity [bps/Hz/cell]	DL	2-by-2	1.69	2.4	–
		4-by-2	1.87	2.6	2.2(*)
		4-by-4	2.67	3.7	–
	UL	1-by-2	0.74	1.2	–
		2-by-4	–	2.0	1.4(*)
Cell-edge user throughput [bps/Hz/cell/user]	DL	2-by-2	0.05	0.07	–
		4-by-2	0.06	0.09	0.06(*)
		4-by-4	0.08	0.12	–
	UL	1-by-2	0.024	0.04	–
		2-by-4	–	0.07	0.03(*)

(*)Required values in base coverage urban environment

3 LONG TERM EVOLUTION STANDARD

Long Term Evolution 'LTE' has become a widely known brand name for the 3GPP-defined successor technology of third-generation mobile systems. LTE stands for Long Term Evolution and originally denoted a work item in 3GPP aimed at developing a successor to the third-generation radio technology. Gradually it came to denote first the new radio technology itself, then also encompassed the radio access network (→ EUTRAN), and is now also used for the entire system succeeding third-generation mobile systems (→ SAE, →EPS) including also the evolved core network (→ EPC), as a quick search for the term LTE on the 3GPP home page [3GPP] will reveal. The 3GPP LTE also called release 8 specification defines the basic functionality of a new, high-performance air interface providing high user data rates in combination with low latency based on MIMO, OFDMA and an optimized system architecture evolution (SAE) as main enablers [4].

4 KEY ENABLING TECHNOLOGIES AND FEATURE OF LTE

This paper provides technical information about two main LTE enabling technologies. The areas covered range from basic concepts to research-grade material, including future directions. The three main LTE enabling technologies are:

4.1 LTE Downlink System Model

One of the key differences between 3G systems and LTE is the use of orthogonal frequency division multiplexing as shown in Figure 1, 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 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 frequency division duplexing (FDD) mode of LTE each OFDM symbol is transmitted over subcarriers of 15 or 7.5 kHz.

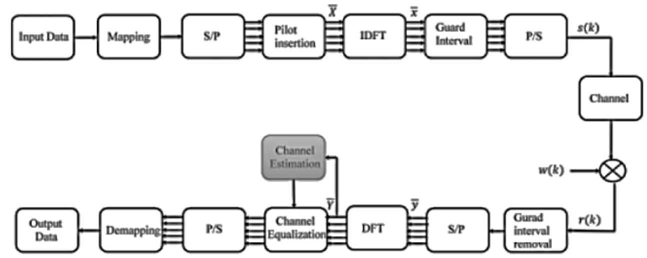

Figure 1 OFDM baseband system [5]

4.2 LTE Uplink System Model

An SC-FDMA uplink transmitter is shown in Figure 2; 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 peak to average power ratio, thus decreasing the power consumption in the user terminals [6].

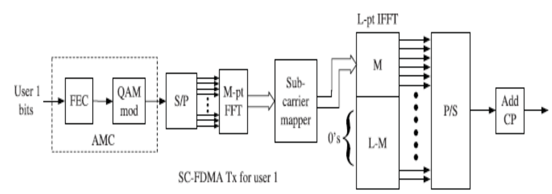

Figure 2 SC-FDMA uplink transmitter for user1, where user 1 is allocated subcarriers 1,2,…, M of L total subcarriers

4.3 Multiple-Input Multiple-Output (MIMO)

The transmission diversity allows us to improve the link performance when the channel quality cannot be tracked at the transmitter which is the case for high mobility UEs. The transmission diversity is also useful for delay-sensitive services that cannot afford the delays introduced by channel-sensitive scheduling. The transmission diversity, however, does not help in improving the peak data rates as a single data stream is always transmitted. The multiple transmission antennas at the eNB is a combination with multiple receiver antennas at the UE which can be used to achieve higher peak data rates by enabling multiple data stream transmissions between the eNB and the UE using MIMO spatial multiplexing. Therefore, in addition to larger bandwidths and high-order modulations, MIMO spatial multiplexing is used in the LTE system to achieve the peak data rate targets. The MIMO spatial multiplexing also provides improvement in cell capacity and throughput as UEs with good channel conditions can benefit from multiple streams transmissions. Similarly, the weak UEs in the system benefit from beam-forming gains provided by precoding signals transmitted from multiple transmission antennas [7]. MIMO is one of the most important means to achieve the high data rate objectives for LTE is multiple antenna transmission. In LTE downlink it is supported one, two or four transmit antennas in the eNB and one, two or four receive antennas in the UE. 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. Nevertheless, in LTE uplink although one, two or four receive antennas are allowed in the eNB, only one transmitting antenna is allowed in the UE. Therefore, multiple antennas can be only used to obtain receive diversity.

5 LONG TERM EVOLUTION-ADVANCED STANDARD

The next evolution of LTE, called LTE-Advanced, was triggered by the ITU-R Circular Letter requesting candidate submissions for IMT-Advanced radio interface technologies. The schedule defined by ITU-R calls for a “Complete Technology” submission for June 2009 and a “Final” submission for October 2009. Development of radio interface specification recommendations is targeted to be completed in February 2011 [8].

Release 10 enhances the capabilities of LTE, to make the technology compliant with the International Telecommunication Union’s requirements for IMT-Advanced. The resulting system is known as LTE-Advanced. This paper covers the new features of LTE-Advanced, by focusing on carrier aggregation, peak data rate, mobility and orthogonal frequency division multiple access (OFDMA).

For the most part, the Release 10 enhancements are designed to be backwards compatible with Release 8. Thus a Release 10 base station can control a Release 8 mobile, normally with no loss of performance, while a Release 8 base station can control a Release 10 mobile. In the few cases where there is a loss of performance, the degradation has been kept to a minimum [1].

LTE-Advanced enhanced these features that can be found in the following:

5.1 Carrier Aggregation

The possibility for carrier aggregation was introduced in LTE release 10. In the case of carrier aggregation, multiple LTE carriers, each with a bandwidth up to 20 MHz, can be transmitted in parallel to/from the same terminal, thereby allowing for an overall wider bandwidth and correspondingly higher per-link data rates. In the context of carrier aggregation, each carrier is referred to as a component carrier (CC) as, from an RF point-of-view; the entire set of aggregated carriers can be seen as a single (RF) carrier. The possibility of up to five component carriers, for different bandwidths of up to 20 MHz, can be aggregated allowing for an overall transmission bandwidths up to 100 MHz [9]. A terminal capable of carrier aggregation may receive or transmit simultaneously on multiple component carriers. Each CC can also be accessed by an LTE terminal from the earlier releases that is, component carriers are backwards compatible [10].

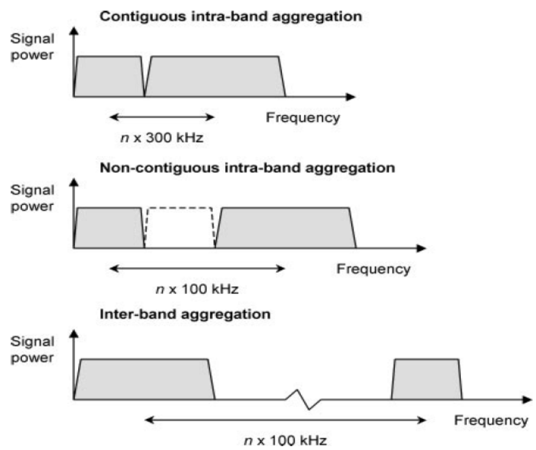

Figure 3 Carrier aggregation scenarios

As noted, that aggregated component carriers do not need to be contiguous in the frequency domain, but rather, with respect to the frequency location of the different component carriers. Three different cases can be identified as shown in Figure 3:

- Intra-band aggregation with frequency-contiguous component carriers
- Intra-band aggregation with non-contiguous component carriers.
- Inter-band aggregation with non-contiguous component carriers.

5.2 Peak Data Rate

LTE-Advanced should support significantly increased instantaneous peak data rates. At a minimum, LTE-Advanced should support enhanced peak data rates to support advanced services and applications (100 Mbps for high and 1 Gbps for low mobility were established as targets for research).

5.3 Mobility

The system shall support mobility across the cellular network for various mobile speeds up to 350 km/h (or perhaps even up to 500 km/h depending on the frequency band). System performance shall be enhanced for 0–10 km/h and preferably enhanced but at least no worse than E-UTRA and E-UTRAN for higher speeds [11].

5.4 Orthogonal Frequency Division Multiple Access (OFDMA)

The block diagram for a downlink OFDMA is shown in Figures 4 and 5.
The basic flow is very similar to an OFDM system except for now K users share the L subcarriers, with each user being allocated M_K subcarriers. Although in theory it is possible to have users share subcarriers, this never occur in practice, so $\sum_k M_k = L$ and each subcarrier only has one user assigned to it [12].

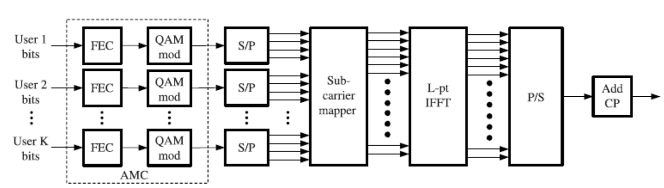

Figure 4 OFDMA downlink transmitter

In OFDM, all subcarriers are assigned to a single user. Hence, for multiple users to communicate with the BS, the set of subcarriers are assigned to each in a Time Division Multiple Access (TDMA) fashion. Alternatively, an OFDM-based multiple access mechanism, namely the OFDMA, assigns sets of subcarriers to different users. In particular, the total available bandwidth is divided into M sets, each consisting of L subcarriers.

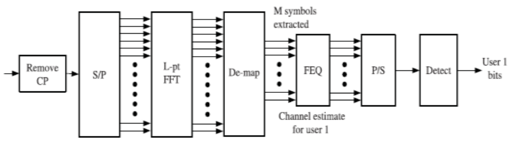

Figure 5 OFDMA downlink receiver for user 1

Despite the relatively straight forwardness of OFDMA, it has very attractive advantages. Probably the most important of these is its inherent exploitation of frequency and multiuser diversities. Frequency diversity is exploited through randomly distributing the subcarriers of a single user over the entire band, reducing the probability that all the subcarriers of a single user experience deep fades. Such allocation is particularly the case when distributed subcarrier assignment is employed. On the other hand, multiuser diversity is exploited through assigning contiguous sets of subcarriers to users experiencing good channel conditions [13]. Another important advantage of OFDMA is its inherent adaptive bandwidth assignment. Since the transmission bandwidth consists of a large number of orthogonal subcarriers that can be separately turned on and off; wider transmission bandwidths, as high as 100 MHz, can be easily realized.

6 LTE-ADVANCED TECHNOLOG-IES

LTE-Advanced maintains backward compatibility with LTE, while achieving higher system performance than LTE and satisfying the minimum requirements for IMT-Advanced, which is in the process of being standardized by the ITU-R. In order to achieve these goals, radio interface technologies such as support of wider transmission bandwidth, enhancement of MIMO technology used and relay, are being studied on a base of LTE technology; in the following some examples of technologies considered for LTE-Advanced are outlined.

1. Multiple Users MIMO.
2. Coordinated multi-point transmission (CoMP).

6.1 Multiple Users MIMO

Figure 6 shows a slightly different technique. Here, two transmit and two receive antennas are sharing the same transmission times and frequencies, in the same way as before [1].

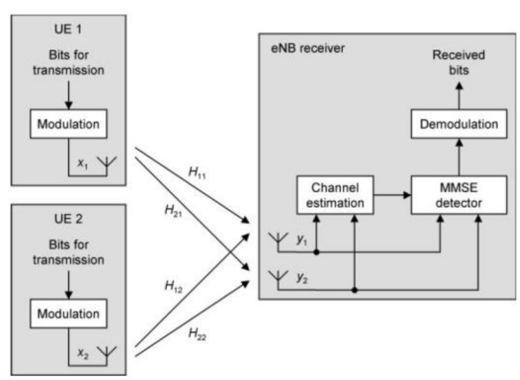

Figure 6 Uplink multiple user MIMO

This time, however, the mobile antennas are on two different mobiles instead of one. This technique is known as multiple users MIMO (MU-MIMO), in contrast with the earlier spatial multiplexing techniques, which are sometimes known as single user MIMO (SU-MIMO).

Figure 6 specifically shows the implementation of multiple users MIMO on the uplink, which is the more common situation. Here, the mobiles transmit at the same time and on the same carrier frequency, but without using any precoding and without even knowing that they are part of a spatial multiplexing system. The base station receives their transmissions and separates them using (for example) the minimum mean square error detector as noted earlier.

This technique only works if the channel matrix is well behaved, but can usually guarantee this for two reasons. Firstly, the mobiles are likely to be far apart, so their ray paths are likely to be very different. Secondly, the base station can freely choose the mobiles that are taking part, so it can freely choose mobiles that lead to a well-behaved channel matrix.

Uplink multiple user MIMO does not increase the peak data rate of an individual mobile, but it is still beneficial because of the increase in cell throughput. It can also be implemented using inexpensive mobiles that just have one power amplifier and one transmit antenna, not two. For these reasons, multiple user MIMO is the standard technique in the uplink of LTE Release 8: single user MIMO is not introduced into the uplink until Release 10.

Multiple user MIMO can be also applied to the downlink, as shown in Figure 7. In this case, however, there is a problem, where Mobile 1 can measure its received signal y_1 and the channel elements H_{11} and H_{12}, in the same way as before.

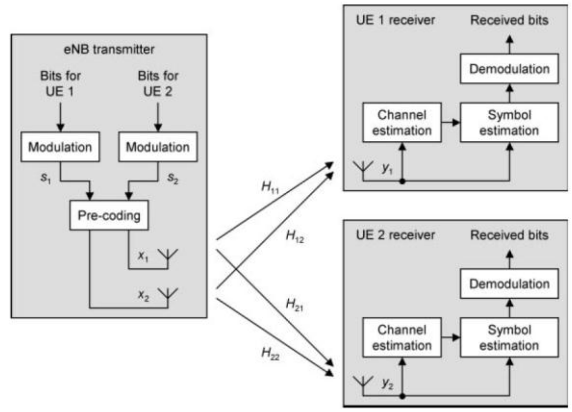

Figure 7 Downlink multiple user MIMO

However, it has no knowledge of the other received signal y_2, or of the other channel elements H_{21} and H_{22}. The opposite situation applies for mobile 2. Neither mobile has complete knowledge of the channel elements or of the received signals, which invalidates the techniques used.

6.2 Coordinated Multi-Point transmission (CoMP)

One of the issues being addressed beyond Release 10 is coordinated multipoint (CoMP) transmission and reception [14, 15]. This is a wide-ranging term, which refers to any type of coordination between the radios communications that are taking place in nearby cells. Its aim is to increase the data rate at the cell edge and the overall throughput of the cell.

There are two main varieties, which will be described from the viewpoint of the downlink. (Similar issues apply on the uplink as well.) In coordinated scheduling and beamforming (CS/CB), a mobile receives data from one cell at a time, its serving cell.

However, the serving cell can coordinate its scheduling and beamforming processes with those of cells nearby, so as to minimize the inter-cell interference.

For example, a cell can configure its beamforming pattern on the sub-carriers that a mobile in a neighboring cell is using, so as to place that mobile in a null. In joint processing (JP), a mobile receives data from multiple cells. These cells can be controlled by one base station, which is not too hard to implement. Alternatively, the cells can be controlled by multiple base stations, which offer better performance but makes issues such as backhaul and synchronization far harder.

The cells used for joint processing can transmit the same data stream as each other, in which case they are operating as diversity transmitters. (The same technique is used for soft handover in UMTS.) Alternatively, they can transmit different data streams, in an implementation of spatial multiplexing that is known as cooperative MIMO as shown in Figure 8.

This has some similarities with multiple users MIMO, but instead of separating the mobile antennas onto two different devices, the network's antennas are separated onto two different cells.

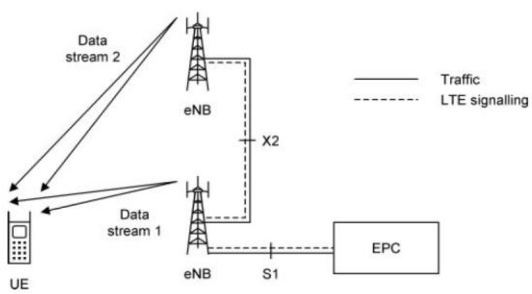

Figure 8 Cooperative MIMO on the LTE-Advanced downlink

7 SUMMARY AND DISCUSSION

Through this paper, a detail description is presented related to the technologies precedent to LTE technology (Release 8). According to the comparison of LTE with different existing technologies, LTE will provide wireless subscribers with significant advantages in traditional and non-traditional wireless communication over those currently provided via existing 3G technologies. LTE offers scalable bandwidths, from 1.4 up to 20 MHz, together with support for both FDD paired and time division duplexing (TDD) unpaired spectrum. LTE will be available not only in the next-generation mobile phones, but also in notebooks, ultra-portables, cameras, camcorders, MBRs, and other devices that benefit from mobile broadband. While LTE-Advanced helps in integrating the existing networks, new networks, services, and terminals to suit the escalating user demands.

The technical features of LTE-Advanced may be summarized with the word integration. LTE-Advanced will be standardized in the 3GPP specification Release 10 and will be designed to meet the 4G requirements as defined by ITU. LTE-Advanced as a system needs to take many features into consideration due to optimizations at each level which involve lots of complexity and challenging implementation. Numerous changes in the physical layer can be expected to support larger bandwidths with more flexible allocations and to make use of further enhanced antenna technologies. Coordinated base stations, scheduling, MIMO, interference management, and suppression will also require changes in the network architecture.

8 CONCLUSIONS

In conclusion, both LTE and LTE Advanced offer high speed access to internet, with high speed internet connection on mobile, where users can enjoy voice calls, video calls, and high speed downloads or uploads of any data and watch internet TV in live or on demand services. The main targets for this evolution are increased data rates, improved spectrum efficiency, improved coverage, reduced latency and packet-optimized system that support multiple Radio Access Technologies. The paper has presented a study on evolution LTE toward LTE-Advanced in terms of LTE enabling technologies (Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO)), also focused on LTE-Advanced technologies (MIMO enhancements for LTE-Advanced, carrier aggregation, peak data rate, mobility and coordinated multi-point transmission (CoMP). LTE-Advanced is a very flexible and advanced system, further enhancements to exploit spectrum availability and advanced multi-antenna techniques.

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