AN OVERVIEW OF LTE AND LTE-A

SUMMARY

This document provides an overview of the Long Term Evolution (LTE) and LTE-Advanced (LTE-A) specifications for digital cellular communications. LTE was based on the International Mobile Telecommunications Release 8 Specification in 2008 (IMT-8) and was originally considered to be a fourth generation (4G) system. Subsequently an enhanced version, LTE-A, was released in 2011 as IMT-10. To most observers this became 4G and LTE was ‘demoted’ 3.9G. Some useful references are provided for the reader requiring more detailed information.

Chris Angove

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ACRONYMS AND ABBREVIATIONS

Table 1-1 Acronyms and Abbreviations

Acronym/Abbreviation	**Meaning**
3.5G, 3.9G	inter-generation (3G and 4G) designations for cellular mobile communications
3G	Third Generation (of cellular mobile communications)
3GPP	Third Generation Partnership Project
4G	Fourth Generation (of cellular mobile communications)
64QAM	64 order QAM (m=64, k=6)
CDMA	code division multiple access
DL	downlink
Gbit/s	gigabits per second
GPRS	General Packet Radio Service
HSDPA	High Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
IEEE	Institution of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
eNodeB	E-UTRAN NodeB
E-UTRAN	Evolved UTRAN
UTRAN	Universal Terrestrial Radio Access Network
ITU	International Telecommunications Union
ITU-R	ITU Radio Division
km/h	kilometres per hour
LTE	Long Term Evolution
LTE-A	Long Term Evolution (Advanced)
Mbit/s	megabit per second
Mcps	megachips per second
MHz	megahertz
MIMO	multiple in multiple out (antenna technologies)
MISO	multiple in single out (antenna technologies)
ms	millisecond
OFDM	orthogonal frequency division multiplex
OFDMA	orthogonal frequency division multiple access
PAPR	peak to average power ratio
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift keying
SC-FDMA	single carrier frequency division multiple access
SIMO	single in multiple out (antenna technologies)
SISO	single in single out (antenna technologies)
TD-SCDMA	time division synchronous CDMA
UL	uplink
UMTS	universal mobile telecommunications service
USA	United States of America
UT	user terminal
WiMAX	Worldwide Interoperability for Microwave Access

1. LONG TERM EVOLUTION (LTE)

This chapter addresses Long Term Evolution (LTE) as distinct from Long Term Evolution – Advanced (LTE-A) which is discussed in Chapter 2.

- LTE was developed by the 3rd. Generation Partnership Project (3GPP) to meet the requirements of the International Telecommunications Union (ITU), in particular the radio group (ITU-R) for International Mobile Telecommunications (IMT) [5].
- Originally, LTE was (informally) referred to as the 4th. generation (4G) mobile cellular communications. Subsequently when LTE-A was released (Section 2), this became 4G and LTE was 'demoted' to 3.9G [6].
- Here, the word 'evolution' refers to evolution of the services from the Universal Mobile Telephone Service (UMTS), originally released in 2000 as IMT-99 and commonly called the third generation mobile communications (3G).
- The 3G and 4G services will co-exist probably for several years until:
    - Frequency spectrum and commercial conditions allow the 4G services to be fully rolled out.
    - The 3G equipment becomes due for upgrading.
- During the changeover, LTE/LTE-A user terminals (UTs) will be designed to allow seamless handover between the (now legacy) 3G services and LTE/LTE-A, depending on the network capacity.

1.1 Key Changes from 3G [7]

1. Multiple antenna technologies.
2. Uplink (UL): orthogonal frequency division multiple access (OFDMA).
3. Downlink (DL): orthogonal frequency division multiple access (OFDMA).

1.2 Objectives [7]

1. Reduced cost/bit.
2. Better service provisioning.
3. Flexible use of existing and new frequency bands.
4. Simplified network architectures.
5. Reduced terminal complexity and power consumption.
6. Support for a range of cell radii ranging from approximately 100 m to 100 km.

1.3 Summary of Requirements [7] [8]

1. Scalable channel bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz with OFDM subcarrier spacing of 15 kHz.
2. Improved spectral efficiency.
3. Increased peak uplink and downlink data rates compared to 3G. For example, those for a 20 MHz bandwidth, FDD under ideal radio propagation conditions are shown in Table 1-1
4. Reduced packet latency, less than 5 ms.
5. Doppler sufficient to tolerate relative speeds up to 350 km/h or 500 km/h, depending on the allocated frequency band.

6. Co-existence with legacy standards.

Table 1-1 Peak downlink and uplink data rates for the LTE 20 MHz bandwidth allocation

Downlink Peak Data Rate for 64 QAM Modulation			
Antenna configuration	SISO	MIMO (2x2)	MIMO (2x2)
Peak data rate (Mbit/s)	100	172.9	326.4
Uplink Peak Data Rates (Single Antenna)			
Modulation	QPSK	16QAM	64QAM
Peak data rate (Mbit/s)	50	57.6	86.4

1.4 Mobility

LTE was primarily designed for ‘low mobile’ (walking, 0 to 15 km/h) and ‘moderate mobile’ (vehicular, 15 to 120 km/h) speeds. The data channel capacity at high mobile speeds, up to 350 km/h is included but the performance is heavily reduced.

1.5 Competing Service

There was only one fully developed competitor to LTE which was proposed by the Institution of Electrical and Electronics Engineers (IEEE), also known as Worldwide Interoperability for Microwave Access (WiMAX). The original WiMAX specification (IEEE 802.16) was aimed at providing fixed and low cost broadband connections to business and domestic premises by replacing the ‘last mile’ of the ‘plain old telephone service’ (POTS). It has since evolved to target high capacity mobile services. The latest WiMAX specification at suffix ‘M’ (IEEE 802.16M) is the mobile version of WiMAX, with comparable performance to LTE and LTE-A.

1.6 Radio Interface

Access is allowed using frequency division duplex (FDD) or time division duplex (TDD), each with its own frame structure and allocated bandwidths from 1.4 MHz to 20 MHz [8].

1.7 Frequency Bands

These are mainly common with the former UMTS bands. Frequency allocations range from approximately 700 MHz to 2700 MHz with contiguous bandwidths from approximately 15 MHz to 70 MHz. Bandwidth is also being released from the upgrade of other communication services, for example the former analog TV and radio terrestrial bands.

For LTE, both downlink and uplink access is via orthogonal frequency division multiple access (OFDMA). Modulation using OFDMA has been understood for some time but not until recently has the processing power been available on battery operated devices to exploit it. One drawback of OFDMA on the uplink is the appreciable peak to average power ratio (PAPR) required, which is challenging for a battery powered UT. This was addressed in the LTE-A specification (Chapter 2) by using single carrier frequency division multiple access (SC-FDMA). This has a smaller PAPR and is more suited to battery powered devices.

1.8 Disadvantages of OFDMA

1. The close spacing of subcarriers (typically 15 kHz) makes them sensitive to frequency errors and phase noise.
2. Doppler shift occurs, particularly with medium and fast mobile stations.
3. High peak to average power ratio (PAPR), increasing the mobile UT requirements.
4. This is less resilient than the CDMA formats as used on 3G, at the cell edges. CDMA uses scrambling codes.

1.9 Multiple Antenna Technologies

LTE was designed at the outset to utilise more than one antenna at the base station (usually called a eNodeB in LTE) but the user terminal (UT) was anticipated to be a handheld mobile device with a limited (battery) powered capability and available space. The UT was therefore assumed to use a single antenna. (The LTE-A release described in Chapter 2 allows up to 4 antennas on the UT).

The LTE base station may use up to 4 antennas. This provides scope for:

1. Path diversity (spatial separation).
2. Beam steering.
3. Spatial multiplexing.

There are 4 generic multi-antenna configurations which are shown schematically in Figure 1-1:

1. Single in single out (SISO).
2. Multiple in single out (MISO).
3. Single in multiple out (SIMO).
4. Multiple in multiple out (MIMO).

Previous mobile services assumed the user terminal (UT) would have one antenna but LTE and LTE-A allow scope for the advantages of more antennas, including fixed station operation. More information is provided in Chapter 2.

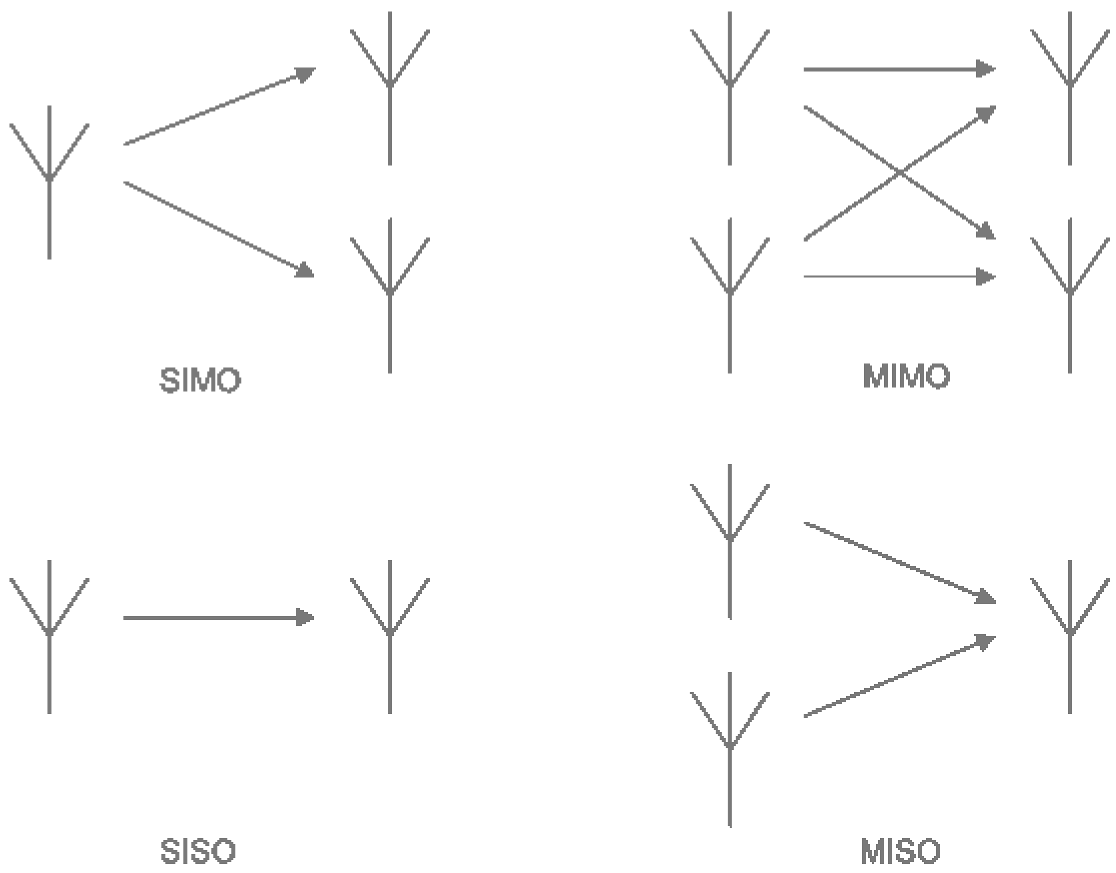

Figure 1-1 Schematics of some multiple antenna configurations assuming a maximum of 2 at either terminal. More antennas are supported under LTE-A

2. LONG TERM EVOLUTION – ADVANCED (LTE-A)

This chapter addresses Long Term Evolution – Advanced (LTE-A) as distinct from Long Term Evolution (LTE) which is discussed in Chapter 1. The 'original' LTE (not advanced) was informally known as 4G until LTE-A was released, then LTE-A became 4G and LTE was considered 'demoted' to 3.9G.

Implementation tests of the LTE specifications found that the predicted peak data rates, particularly for mobile stations, could not be achieved. More effective bandwidth was required.

2.1 Background

International Mobile Telecommunications (IMT) standards are generated by the 3G Partnership Project (3GPP) in response to requirements from the International Telecommunications Union Radio Group (ITU-R). Starting with the original 3G Universal Mobile Telephone Service (UMTS), they are widely known by their IMT release number nn or n (IMT-nn or IMT-n respectively) as follows [5] [7]:

- IMT-99 (2000): UMTS 3.84 Mcps, W-CDMA (FDD and TDD).
- IMT-4 (2001): 1.28 Mcps TDD (TD-SCDMA).
- IMT-5 (2002): HSDPA.
- IMT-6 (2005): HSUPA.
- IMT-7 (2007): HSPA+ (64QAM DL, 16QAM UL, MIMO). LTE feasibility study.
- IMT-8 (2008): LTE released.
- IMT-9 (2009): LTE-A feasibility study.
- IMT-10 (2011): LTE-A released, also known as IMT Advanced.

2.2 Key Improvements of LTE-A Compared to LTE:

1. Wider *effective* bandwidths allowing faster peak data rates using carrier aggregation.
2. Improved uplink multiple access.
3. Improved multiple antenna operation.

2.3 Objectives of LTE-A

1. Enhanced peak data rates: up to 1 Gbit/s (4x4 MIMO) low mobility, 100 Mbit/s high mobility. (This is a substantial increase from 3G UMTS for which the respective rates were 2 Mbit/s and 144 kbit/s).
2. Backward compatibility with LTE.
3. Common functionality worldwide.
4. Interworking with other radio systems.
5. High quality mobile performance.
6. User friendly applications.
7. Worldwide roaming.

2.4 Spectrum Allocations and Carrier Aggregation

Many of the LTE and LTE-A uplink and downlink frequency bands were inherited from 3G UMTS services, with some more recent additions from the former analog terrestrial broadcast bands [8]. For the faster LTE-A services, allowing for the achievable spectral efficiencies the required bandwidths may exceed the contiguous bandwidth allocations, particularly for mobile services. LTE-A requires the equivalent channel bandwidth to extend to 100 MHz. However, radio frequency spectrum is scarce, expensive and reference to some typical LTE/LTE-A frequency allocations for Europe and the USA in Table 2-1 shows that no allocation is as great as 100 MHz. In fact some are as small as 11 MHz to 18 MHz. Carrier aggregation, which was introduced with LTE-A, allows smaller bandwidths such as these to be combined using either of the following methods: intra-band contiguous, intra-band non-contiguous, inter-band non-contiguous.

- Intra-band contiguous.

The operational bandwidth comprises two or more frequency bands which are adjacent within the same allocated frequency band.

- Intra-band non-contiguous.

The operational bandwidth comprises two or more frequency bands which are not adjacent but within the same allocated frequency band.

- Inter-band non-contiguous.

The operational bandwidth comprises two or more frequency bands which are in different allocated frequency bands and therefore are not adjacent.

For example, referring to Table 2-1, an inter-band non-contiguous allocation of 100 MHz could be made with the full LTE 2600 Europe allocation (70 MHz) and 30 MHz from the LTE 800 Europe allocation (32 MHz).

A LTE-A UT with carrier aggregation capability would require multiple transceivers according to which frequency bands are used. Chipsets are available to the UT manufacturers which may be programmed to selections from several uplink and downlink frequency bands.

Table 2-1 Some LTE/LTE-A frequency allocations in Europe and the USA

Service Name	**Bandwidth (MHz)**	**Link Frequency Relationship**	**Frequency (MHz)**			
			Uplink		**Downlink**	
			Lower	**Upper**	**Lower**	**Upper**
EGSM 900 (Europe)	35	DL>UL	880	915	925	960
DCS 1800 (Europe)	75	DL>UL	1710	1785	1805	1880
UMTS 2100 (Europe)	60	DL>UL	1920	1980	2110	2170
LTE 2600 (Europe)	70	DL>UL	2500	2570	2620	2690
LTE 800 (Europe)	32	UL>DL	830	862	789	821
Cellular 800 (USA)	25	DL>UL	824	849	869	894
SMR 800 (USA)	18	DL>UL	806	824	851	869
PCS 1900 (USA)	60	DL>UL	1850	1910	1930	1990
AWS 1700 (USA)	45	DL>UL	1710	1755	2110	2155
LTE 700 (12) (USA)	18	DL>UL	698	716	728	746
LTE 700 (13) (USA)	11	UL>DL	776	787	746	757

2.5 Service Categories

With the increased effective operating bandwidth of LTE-A, extra capacity is achievable compared to LTE, so an extra three categories for faster uplinks and downlinks were added: categories 6, 7 and 8. Category 8 caters for downlink and uplink speeds of 1.2 Gbit/s and 600 Mbit/s respectively. This service level requires static stations and full multiple antenna implementations.

2.6 Enhanced Uplink and Downlink Multiple Access

The uplink uses single carrier frequency division multiple access (SC-FDMA), introduced with LTE-A, and the downlink uses orthogonal frequency division multiple access (OFDMA). SC-FDMA has a smaller peak to average power ratio (PAPR) than OFDMA and therefore is more suited to battery powered devices. LTE required contiguous frequency blocks for the uplink whereas LTE-A allows (non-contiguous) clustered SC-FDMA for the uplink. Clustered SC-FDMA is also known as discrete Fourier Transform spread OFDM (DFT-S-OFDM).

2.7 Multiple Antenna Technologies

The maximum antenna allocations for LTE are:

- Downlink transmit: 4 antennas.
- Uplink transmit: 1 antenna.

The maximum antenna allocations for LTE-A are:

- Downlink transmit: 8 antennas.
- Uplink transmit: 4 antennas.

Up to LTE, the size and battery power capability for a *mobile* user terminal (UT) has been assumed to limit it to just one antenna. For LTE-A the UT may have up to 4 antennas, presenting some challenges for a typical mobile UT. For a fixed station UT however with fewer restrictions on power and antenna space, LTE-A has opened potential for very high capacity but fixed position ad-hoc wireless networks. The multipath rich propagation channels common in metropolitan environments has also provided scope for spatial multiplexing. For this, the UT requires one receiver per antenna at the transmit end, up to 4 for LTE or 8 for LTE-A. Each path may then be processed independently in the time domain to recover data from uncorrelated channels, a natural result of multipath fading.

Where space exists at a fixed station UT, it may be possible to intentionally separate the antennas to increase de-correlation and thereby increase the overall channel capacity. Another option might be to use orthogonal polarisations.

2.8 Comparison of OFDMA and SC-FDMA

These may be compared with the help of the schematic shown in Figure 2-1. This shows the OFDMA and SC-FDMA spectra in 3 dimensions in terms of amplitude (voltage), time and frequency. Typically both cases will have a subcarrier frequency spacing of 15 kHz. The OFDMA subcarriers will all be of the same amplitude but the SC-FDMA subcarriers will be differing amplitudes as shown. It assumes that quadrature phase shift keying (QPSK) is used with 4 possible symbols A (red), B (green), C (yellow) and D (blue) representing the 4 positions as indicated on the IQ diagram. Suppose that it is required to send symbols in the following order: ABCDBADC. The OFDMA symbols will be send in groups of 4 (ABCD followed by BADC) and the SC-FDMA symbols will be sent singly (ABCDBADC).

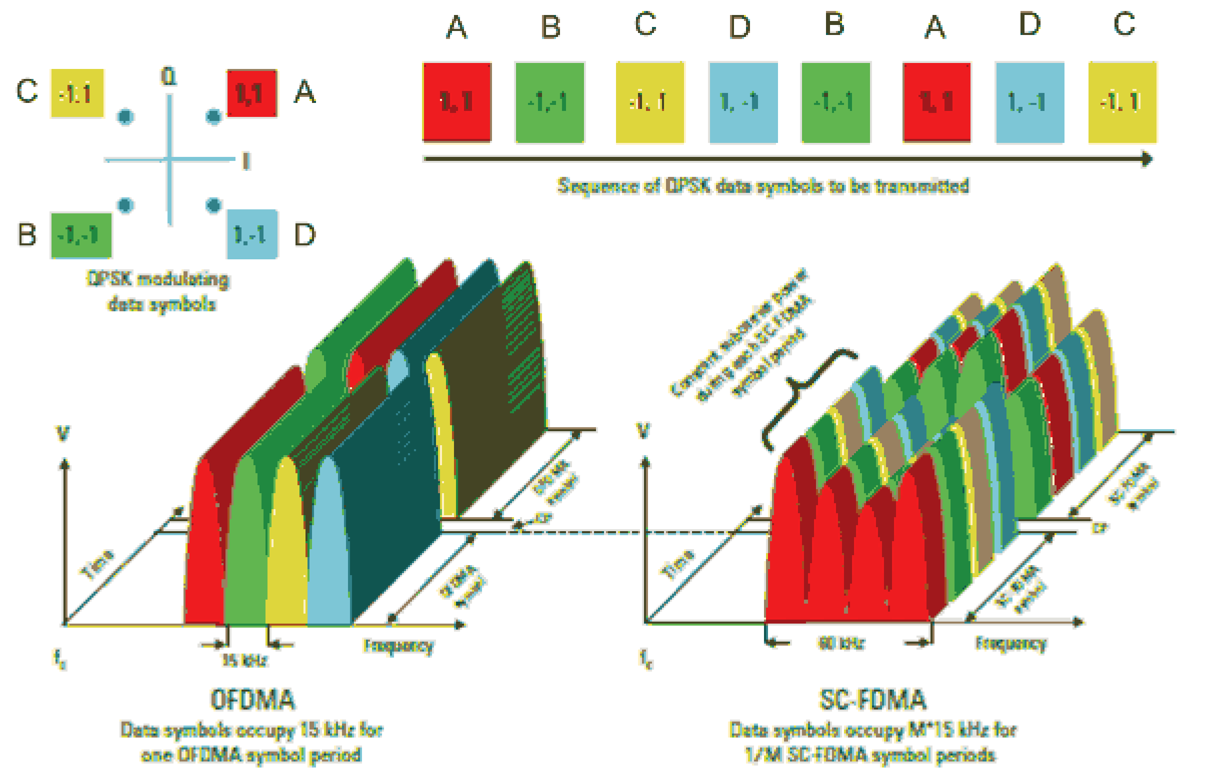

Figure 2-1 An illustration of the transmission of OFDMA and SC-FDMA in the combined voltage, frequency time plane

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[5] Agilent Application Note 5990-6706EN (op. cit): p1, pp 3 – 4.

[6] Dahlman, Erik; Parkvall, Stefan and Skold, Johan (op. cit): p 1.

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[8] Agilent Application Note 5990-6706EN (op. cit): pp 11 - 18.

[9] Dahlman, Erik; Parkvall, Stefan and Skold, Johan (op. cit): pp xvii – xxiv.