

A Survey of Long Term Evolution

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Abstract

Long Term Evolution (LTE) is a significant project of 3rd Generation Partnership Project (3GPP), initially proposed on the Toronto conference of 3GPP in 2004 and officially started as LTE work item in 2006. LTE, as a transition from the 3rd generation (3G) to the 4th generation (4G), has achieved great capacity and high speed of mobile telephone networks without doubt. It defines a new packet-only wideband radio with flat architecture and assumes a full Internet Protocol (IP) network architecture in order to assure voice supported in packet domain in design. In addition, it is combined with top-of-the-line radio techniques in order to gain better performance than Code Division Multiple Access (CDMA) approaches. LTE provides scalable carrier bandwidths from 1.4 MHz to 20 MHz and frequency division duplex (FDD), as well as time division duplex (TDD). In this paper, it presents an overall description of LTE technology separately in different aspects of LTE architecture and technical principles to clarify how LTE as a radio technology achieves a high performance for cellular mobile communication systems.

Keywords: LTE, Downlink, Uplink, OFDMA, SC-FDMA, MIMO, TDD, FDD, LTE architecture, LTE performance

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1. Introduction

As Internet generation accustomed to access broadband wherever they go, mobile broadband, instead of only at home and in the office, has become a reality. Therefore, the Global System for Mobile Communications family constantly develops new mobile technologies to achieve better performance, such as higher speed, larger capacity and so forth. LTE is a step beyond 3G and towards the 4G, evolved after EDGE, UMTS, HSPA and HSPA Evolution. The contributions of LTE make sure that the users are able to request more mobile applications like interactive TV, mobile video blogging, advanced games or professional services.

In this paper, it covers a relatively detailed LTE overview in the second section, which is primarily described around its background, technology, specifications. In section three, it aims to LTE technical theories such as LTE architecture, physical and transport channels of Downlink (DL) and Uplink (UL), multiple access principles (OFDMA and SC-FDMA), MIMO, also LTE duplex schemes. As followed by the fourth section, it explicitly shows the performance of LTE, for instance the end user application performance. Finally, a simple summary and conclusion will be provided in section six.

2. LTE Overview

LTE enhanced the Universal Mobile Telecommunication Services (UMTS) in a set of points on account of the future generation cellular technology needs and growing mobile communication services requirements. Such enhancements are generated due to LTE background requirements, motivations and targets, as presented in section 2.1. The brief description about LTE technology and specifications is also covered in the following subsections.

2.1 LTE Background

LTE was proposed in 2004 Toronto conference for the sake of achieving higher speed and lower packets latency in UMTS 3G systems. Hence, LTE has to satisfy a set of high-level requirements, shown as below [Poole07a]:

- a. Reduced cost per bit
- b. Simple architecture and open interfaces
- c. Flexibility usage of existed and future frequency bands
- d. Reasonable terminal power consuming
- e. Enhanced user experience-more services with lower cost and high speed

As for the motivations and targets, 3GPP LTE aims to superior performance compared with HSPA technology. The main performance targets are listed as below [Holma09].

- a. 2 to 4 times more spectral efficiency than HSPA Release 6
- b. Peak rates beyond exceed 100 Mbps in DL and 50 Mbps in UL
- c. Round trip time < 10 ms

- d. Optimized packet-switching
- e. High-level mobility and security
- f. Efficient terminal power-consuming optimized
- g. Flexible frequency with 1.5 MHz to 20 MHz allocations

2.2 LTE Technology

LTE is composed of many new technologies compared with the previous generation of cellular systems. These new technologies are used to generate more efficiency with regards to spectrum and higher data rates as expected by designers. Here are only snapshots of the technologies and they will be clarified in detail in the third section.

- a. OFDM (Orthogonal Frequency Division Multiplex) [Poole07b]: In order to gain high data bandwidth when transmitting packets, LTE integrates OFDM technology which can provide high-degree resilience to reflections and interference at the same time. Furthermore, the access schemes can be divided into two access approaches used in the DL and UL respectively. The first one for the DL is OFDMA (Orthogonal Frequency Division Multiplex Access); the second one for the UL is SC-FDMA (Single Carrier- Frequency Division Multiplex Access), which has the advantages of smaller peak to average power ratio and more constant power able to get high RF power amplifier efficiency in the mobile handsets.
- b. MIMO (Multiple Input Multiple Output) [Holma09] [Poole07c]: MIMO operations include spatial multiplexing as well as pre-coding and transmit diversity. These operations addressed the problems of multiple signals arising from many reflections, which were encountered by previous telecommunications systems. Moreover, using MIMO also increases the throughput via the additional signal paths after those operations. MIMO requires two or more different antennas with different data streams to distinguish the different paths, such as the schemes using 2 x 2, 4 x 2, or 4 x 4 antenna matrices.

2.3 LTE Specification

This subsection focuses on the DL and UL relevant specifications about LTE. The LTE specification limits the DL peak rates of at least 100 Mbps and UL of at least 50 Mbps as well as RAN round-trip times of less than 10 ms. The Table 1 shows the similarities and differences between the operations of the UL and DL, according to the performance they can offer [Poole07a].

Table 1 Parameter and Details between UL and DL operations

PARAMETER	DETAILS
Data type	All packet switched data (voice and data). No circuit switched.
Modulation types supported	QPSK, 16QAM, 64QAM (UL and DL)
Access schemes	OFDMA (DL); SC-FDMA (UL)

Duplex schemes	FDD and TDD
Peak DL speed 64QAM (Mbps)	100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
Peak UL speed (Mbps)	50 (QPSK), 57 (16QAM), 86 (64QAM)
Channel bandwidths (MHz)	1.4, 3, 5, 10, 15, 20
Mobility	0 – 15 km/h (optimized) 15 – 120 km/h (high performance)
Latency	Idle to active less than 100ms Small packets ~ 10ms

To briefly sum up this section, the main advantages of LTE are low latency, high throughput, high speed, great capacity, an enhanced end-user application experience and low operating cost.

3. LTE Technology Theory

This section presents UMTS LTE technology theory, such as LTE architecture, physical and transport channels for DL and UL, multiple access principles (OFDMA, and SC-FDMA), MIMO and TDD/FDD duplex schemes.

3.1 LTE Architecture

The currently agreed LTE architecture adopts a flat architecture, which can be illustrated via four functional elements as below (see also Figure 1) [Motorola07]:

- a. Evolved Radio Access Network (RAN): it mainly consists of a single RAN node named as eNodeB (eNB). The eNB interfaces with the User Equipment (UE) and hosts the physical layer (PHY), Medium Access Control (MAC), Radio Link Control (RLC), and Packet Data Control Protocol (PDCP) layers. Its functions include radio resource management, admission control, scheduling, enforcement of negotiated UL QoS and compression/decompression of DL/UL user plane packet headers.
- b. Serving Gateway (SGW): it performs as the mobility anchor for the user plane during inter-eNB handovers and as the anchor for mobility between LTE and other 3GPP technologies. At the same time, it routes and forwards user data packets. The SGW controls the termination of the DL data path and paging while DL data comes to UE and replicates the user traffic when lawful and rational interception. It also manages and stores UE information, for instance, parameters of the IP bearer service, network internal routing information.
- c. Mobility Management Entity (MME): the key control-node for the LTE access network. It tracks and pages the idle mode UE, even retransmission. MME selects the SGW for a UE at initial attach and at time of intra-LTE handover involving Core Network (CN) node relocation. When authenticating the user, it interacts with the HSS (a master user database supporting IP Multimedia Subsystem and

including subscriber information) [Wiki_HSS] through the specified interface.

- d. Packet Data Network Gateway (PDN GW): it has two key roles in terms of functionality. First, the PDN GW supports the connectivity to the UE and to the external packet data networks via the entry and exit of UE traffic. The other key role of the PDN GW is acting as the anchor for mobility between 3GPP and non-3GPP technologies such as WiMAX and 3GPP2 (CDMA 1X and EvDO).

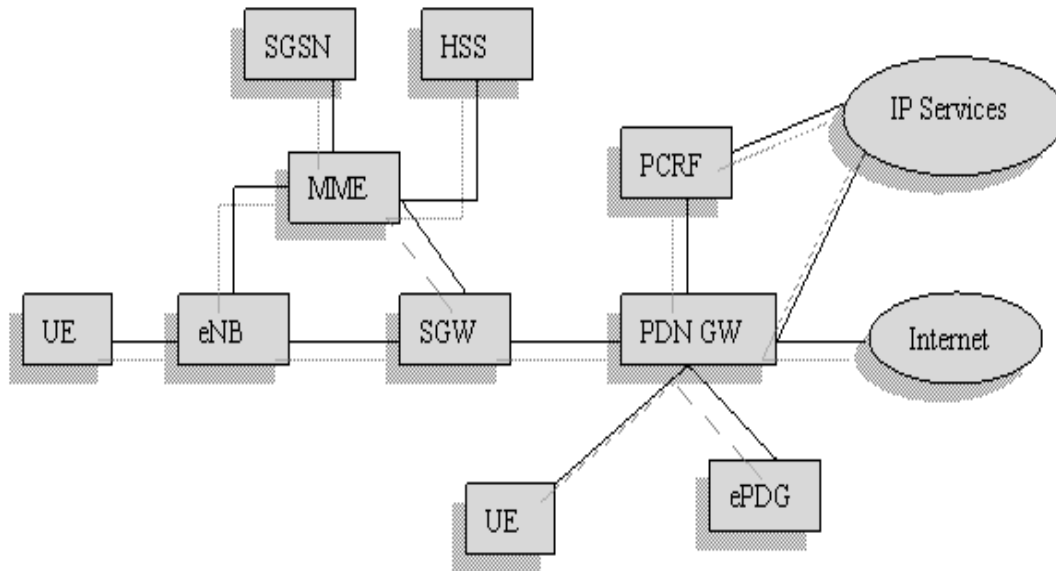


Figure 1: High Level Architecture for 3GPP LTE

The LTE architecture running normally and efficiently must have the well-designed physical and transport channels between DL and UL, since all the packets transmissions are inevitably involved both two links and then how the channels to be designed to enable dynamic resource utilization naturally becomes important. The LTE PHY DL and UL are quite different and treated separately within the specification documents [Zyren07]. Therefore, the physical and transport channels for DL and UL are also different for achieving the different goals in transmission, which are simply introduced in the following subsections.

Physical and Transport Channels for Downlink [Holma09] [Poole07d]

Physical Channels:

- *Physical Broadcast Channel (PBCH)*: It holds the system information for UEs when requiring to access the network.
- *Physical Control Format Indicator Channel (PCFICH)*: This channel is used for managing the transmission format.
- *Physical Downlink Control Channel (PDCCH)*: The purpose of this physical channel is primarily to carry the scheduling information.

- *Physical Hybrid ARQ Indicator Channel (PHICH)* : This channel is used to report the Hybrid ARQ status.
- *Physical Downlink Shared Channel (PDSCH)* : This is used for unicast and paging.
- *Physical Multicast Channel (PMCH)* : This physical channel is to carry system information for multicast purposes.
- *Physical Control Format Indicator Channel (PCFICH)* : It supplies information to decode the PDSCH via UE.

Transport Channels:

- *Broadcast Channel (BCH)* : This transport channel maps to Broadcast Control Channel (BCCH)
- *Downlink Shared Channel (DL-SCH)* : This is the main channel for downlink data transfer, used by many logical channels.
- *Paging Channel (PCH)* : To convey the Paging Control Channel (PCCH)
- *Multicast Channel (MCH)* : To transmit Multicast Control Channel (MCCH) information.

Physical and Transport Channels for Uplink [Holma09] [Poole07d]

Physical Channels:

- *Physical Uplink Control Channel (PUCCH)* : To send Hybrid ARQ acknowledgement
- *Physical Uplink Shared Channel (PUSCH)* : This channel on the UL is the UL counterpart of PDSCH
- *Physical Random Access Channel (PRACH)* : This UL physical channel is for the purpose of random access functions.

Transport Channels:

- *Uplink Shared Channel (UL-SCH)* : Similar as Downlink Shared Channel (DL-SCH).
- *Random Access Channel (RACH)* : To be used for random access requirements.

3.2 LTE Multiple Access Principles

As mentioned in section 2.2, LTE has multiple access principles such as OFDMA for DL and SC-FDMA for UL, which will be discussed in the next subsections.

3.2.1 OFDMA in LTE

The principle of the OFDMA focuses on the usage of narrow, mutually orthogonal sub-carriers [Toskala09]. And the OFDM signal used in LTE consists of a maximum of 2048 different sub-carriers spacing typically 15 kHz [Poole07b] regardless of the

total transmission bandwidth. At the sampling instant of a single sub-carrier and the other sub-carriers having a zero value, different sub-carriers maintain orthogonality [Toskala09]. Then the actual signal is transmitted after the Fast Fourier Transform (FFT) block, used to change between time and frequency domain representation of the signal. In the transmitter side, the OFDMA system uses inverse FFT (IFFT) block to create signals. The data bits through Modulator feed to the Serial-to-Parallel conversion and then to the IFFT block. As shown in Figure 2, the IFFT block goes to the cyclic extension (cyclic prefix), which aims to avoid inter-symbol interference [Holma09].

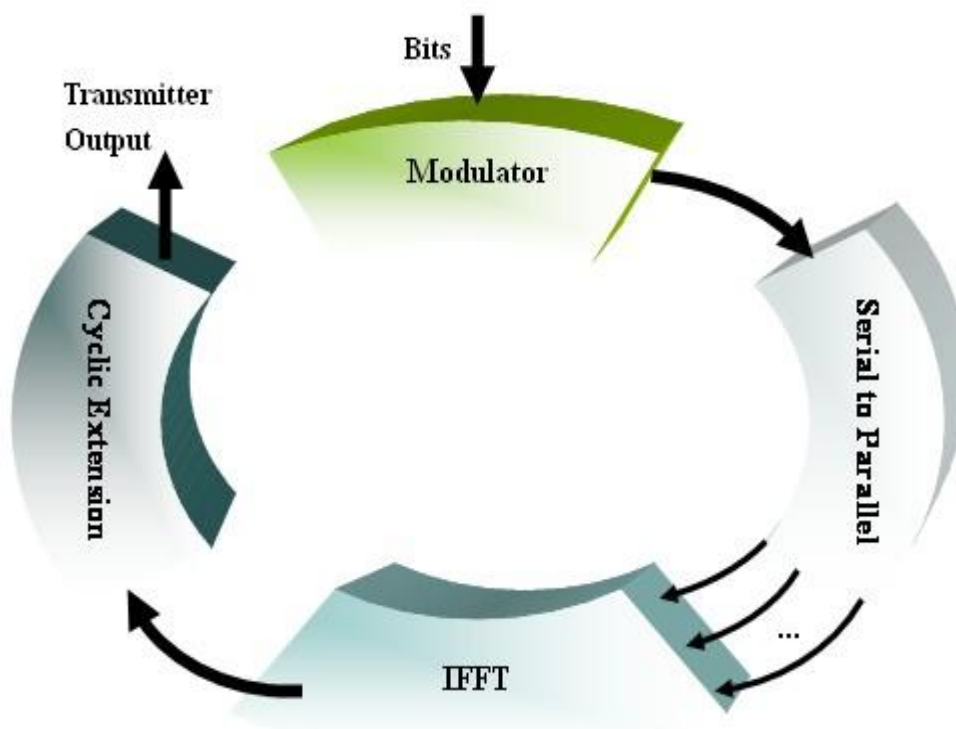


Figure 2: OFDMA Transmitter

In the receiver side (see Figure 3), FFT is used again to convert back from the frequency domain and single signal to the time domain representation of multiple sub-carriers. The equaliser in Figure 3, as a typical solution of receiver reverts the channel impact for each sub-carrier. It refers to the estimator to cancel out the complex-valued multiplication caused by the frequency-selective fading of the channel and does not present a great complexity [Toskala09]. These simple operations are just to multiply each sub-carrier (with the complex-valued multiplication) based on the estimated channel frequency response (the phase and amplitude adjustment each sub-carrier has experienced) of the channel [Holma09].

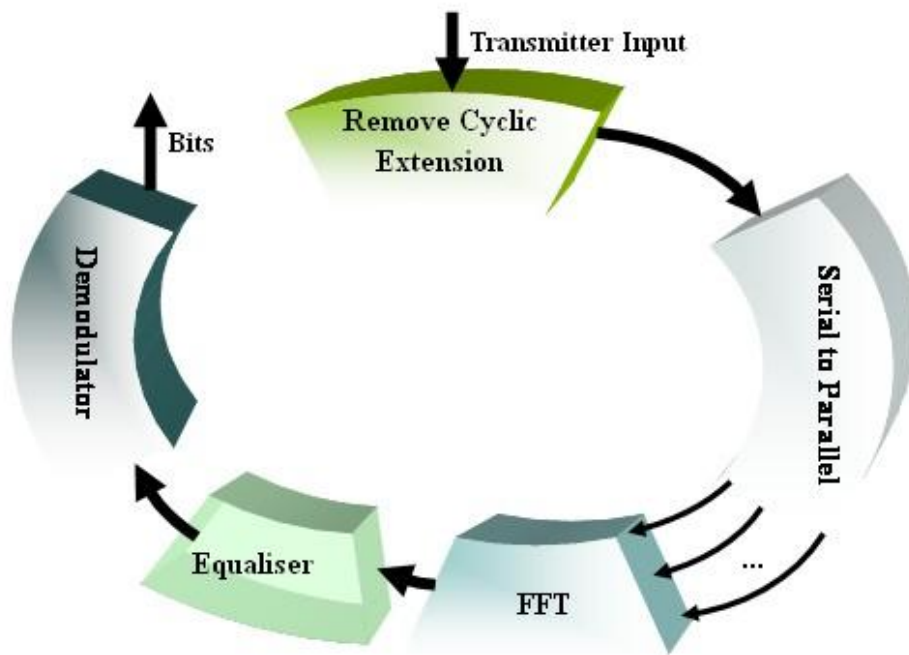


Figure 3: OFDMA Receiver

The OFDMA approach achieves high peak data rates in high spectrum bandwidth and also high flexibility in channelization. LTE therefore enables to boost spectral efficiency and operate in various radio channel sizes from 1.25 MHz to 20 MHz.

3.2.2 SC-FDMA in LTE

In the UL direction, LTE uses SC-FDMA scheme, which is suitable to both FDD and TDD modes. This scheme is actually a hybrid format that combines the low peak to average ratio provided by single-carrier systems with the multi-path interference resilience and flexible sub-carrier frequency allocation that OFDM provides [Poole07b]. In SC-FDMA, the practical transmitter makes use of FFT/IFFT blocks as well to place transmission in the correct position of the transmit spectrum in case of variable transmission bandwidth. The maximum transmission bandwidth is up to 20 MHz, while the minimum transmission bandwidth is down to 180 kHz. In the different uplink frequency blocks, different transmitters use the FFT/IFFT pair to place otherwise equal bandwidth transmissions via adjusting the sub-carrier mapping between FFT and IFFT blocks [Toskala09]. As shown in Figure 4 and 5, the SC-FDMA is pretty similar to the DL OFDMA principle and the need for guard bands among different users can be avoided by adding the OFDMA property of good spectral waveform with a regular QAM modulator. The receiver still needs to process the inter-symbol interference as cyclic prefix prevents inter-symbol interference between a block of symbols [Holma09].

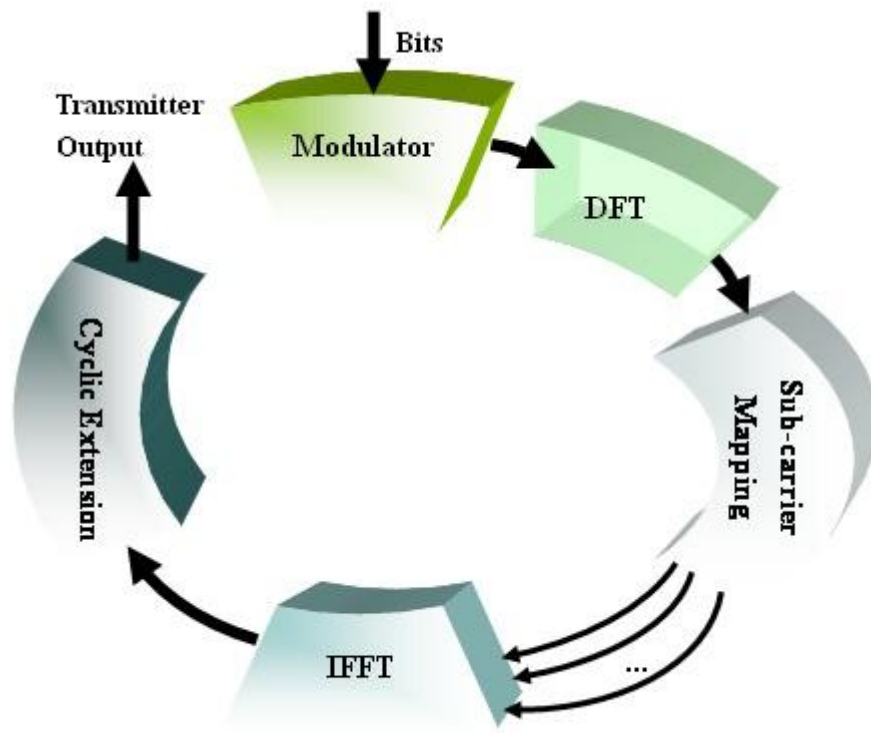


Figure 4: SC-FDMA Transmitter

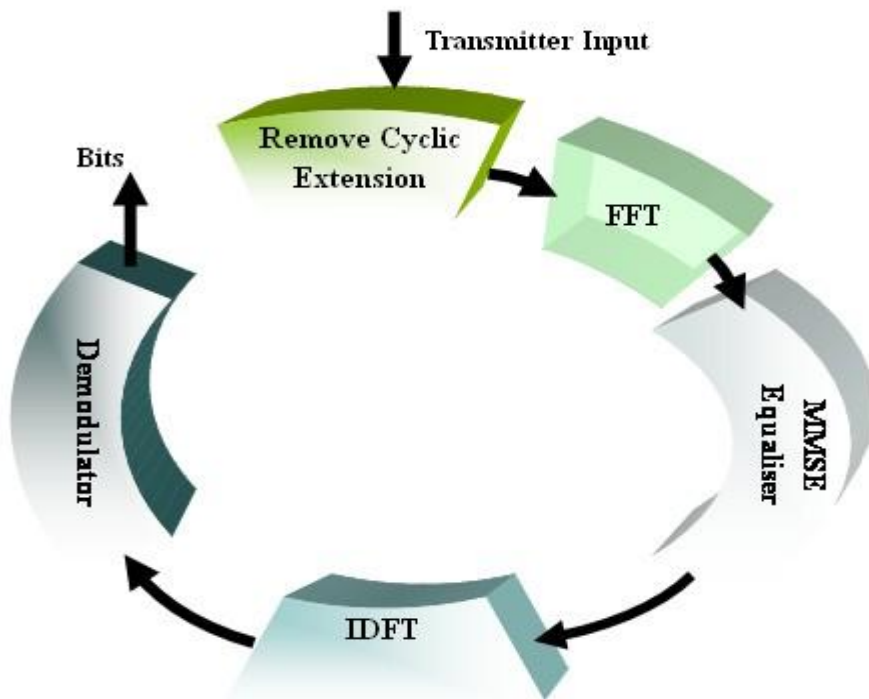


Figure 5: SC-FDMA Receiver

Although LTE UL requirements are different from DL requirements in several aspects, the basic transmitter and receiver architecture of SC-FDMA is nearly identical to that of OFDMA as mentioned above. Figure 6 here presents the functions common to OFDMA and SC-FDMA as well as SC-FDMA only functions, which is more detailed than the former figures of SC-FDMA transmitter and receiver in principle.

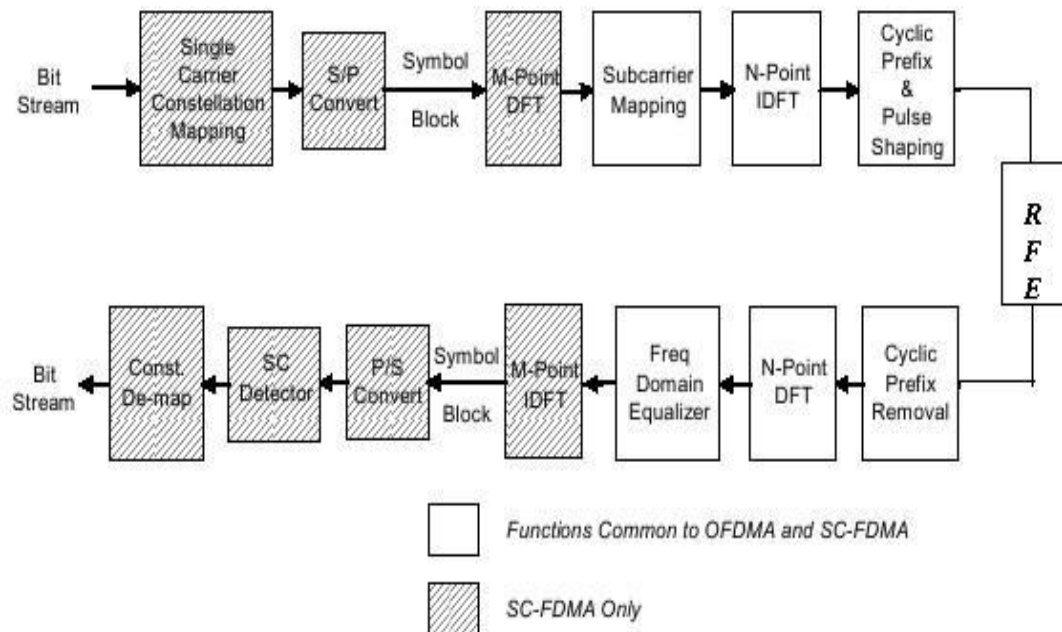


Figure 6: Functional Commonality through SC-FDMA and OFDMA Signal Chains [Zyren07]

3.3 MIMO in LTE

MIMO has a growing usage trend among many high data rate technologies in order to provide great efficiency, such as in Wi-Fi and other wireless and cellular technologies. LTE therefore chooses MIMO to increase the throughput while OFDM changes a frequency selective fading channel into multiple flat fading sub-channels facilitating easy equalization [Ajey10]. Generally, MIMO deploys multiple antennas on the receiver and transmitter to take advantage of multi-path effects to transmit additional data without causing interference. Since there are more terminals than base stations and terminal works cost price is far more sensitive, the MIMO schemes employed in LTE vary slightly on both DL and UL in order to get the low terminal cost.

For the DL, the configurations that two transmitting antennas at the base station and two receiving antennas on the mobile terminal are made as baseline. For the UL, multi-user MIMO (MU-MIMO) [Poole07c] is used to reduce the cost of the mobile, because the configuration for this scheme is only one transmitting antennas on the mobile terminal without considering multiple antennas at the base station. Furthermore, multiple mobile terminals may transmit simultaneously on the same channel or channels, and they cause no interference with each other for the reason to use mutually orthogonal pilot patterns.

The basic principle of MIMO referring to base station is shown in Figure 7; firstly data bits inputted to Demux and Modulation generate different data streams, next they conduct the pre-coding operation and then go towards the signal mapping and generation to form the useful signal needed by the Base station. In the whole process, MIMO utilizes the multi-path signal propagation that exists between the transmitter and receiver to significantly improve the data throughput available on a given channel with its defined bandwidth, according to the real conditions in practice.

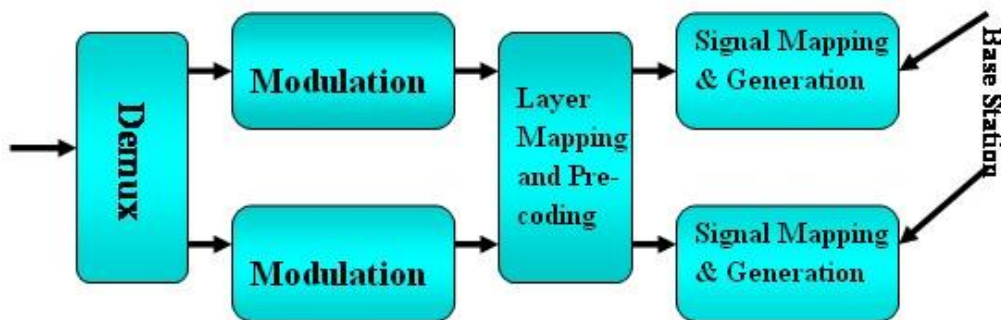


Figure 7: MIMO Principle with 2 x 2 Antennas at Base Station

3.4 LTE TDD and FDD Duplex Schemes

LTE can effectively be deployed in both the unpaired and paired spectrum according to 3GPP Release 8 specifications. The Time Division Duplex (TDD) is operated on the unpaired spectrum, while the Frequency Division Duplex (FDD) is operated on the paired spectrum. These two duplex schemes provide deployment flexibility according to operator preference and spectrum allocation [Ghosh08]. LTE TDD and FDD modes share the same underlying framework and have very few differences as a whole [Holma09]. LTE FDD using paired spectrum plays a role in forming the migration path for the current 3G services. LTE TDD also known as TD-LTE is considered as providing the evolution or upgrade path for Time Division- Synchronous Code Division Multiple Access (TD-SCDMA). Both TDD and FDD LTE modes have their own advantages and disadvantages, which may affect LTE to get different results (see Table 2) [Poole07e].

Table 2: Different Reflections using LTE TDD/FDD

PARAMETER	LTE-TDD	LTE-FDD
Unpaired spectrum	Yes	No
Paired spectrum	No	Yes
Hardware cost	Lower cost and no diplexer needed	Diplexer is needed and cost is higher.

Channel reciprocity	Channel propagation is the same in both directions which enables transmit and receive to use on set of parameters	Channel characteristics different in both directions as a result of the use of different frequencies
UL / DL asymmetry	It is possible to dynamically change the UL and DL capacity ratio to match demand	UL / DL capacity determined by frequency allocation set out by the regulatory authorities. It is therefore not possible to make dynamic changes to match capacity. Regulatory changes would normally be required and capacity is normally allocated so that it is the same in either direction.
Guard period / guard band	Guard period required to ensure uplink and downlink transmissions do not clash. Large guard period will limit capacity. Larger guard period normally required if distances are increased to accommodate larger propagation times.	Guard band required to provide sufficient isolation between uplink and downlink. Large guard band does not impact capacity.
Discontinuous transmission	Discontinuous transmission is required to allow both uplink and downlink transmissions. This can degrade the performance of the RF power amplifier in the transmitter.	Continuous transmission is required.
Cross slot interference	Base stations need to be synchronized with respect to the uplink and downlink transmission times. If neighboring base stations use different uplink and downlink assignments and share the same channel, then interference may occur between cells.	Not applicable

4. LTE Performance

In this section, it will focus on the end user application performance of LTE, especially depending on the bit rate and latency offered by LTE. LTE provides high peak bit rates by using a bandwidth up to 20 MHz, high-order 64QAM and

multi-stream MIMO transmission [Toskala09]. Here assumes 13 data symbols per 1ms sub-frame. The modulation coding is that QPSK carries 2 bits per symbol, 16QAM 4 bits and 64QAM 6 bits; QPSK 1/2 rate coding carries 1 bps/Hz, and 64QAM without coding and with 2 x 2 MIMO carries 12 bps/Hz. The items of the sub-carriers number for each bandwidth are 72 per 1.4 MHz, 180 per 3.0 MHz bandwidth and so forth. The detailed assumptions and results for DL peak bit rates are shown in Table 3, and they can also be calculated from the equation as below:

$$\text{Peak bit rate (Mbps)} = (\text{bits/Hz}) \times \text{Number of sub-carriers} \times (\text{Number of symbols per sub-frame/1ms})$$

The UL peak data rates are shown in Table 4 and the reason why they are lower than DL peak data rates is that single-user MIMO is not specified in UL and MIMO in UL only increases cell data rates [Toskala09].

Table 3: Downlink peak bit rates

Modulation coding		Peak bit rate per sub-carrier/bandwidth				
		72/1.4 MHz	180/3.0 MHz	300/5.0 MHz	600/10 MHz	1200/20 MHz
QPSK 1/2	Single stream	0.9	2.2	3.6	7.2	14.4
16QAM 1/2	Single stream	1.7	4.3	7.2	14.4	28.8
16QAM 3/4	Single stream	2.6	6.5	10.8	21.6	43.2
64QAM 3/4	Single stream	3.9	9.7	16.2	32.4	64.8
64QAM 4/4	Single stream	5.2	13.0	21.6	43.2	86.4
64QAM 3/4	2 x 2 MIMO	7.8	19.4	32.4	64.8	129.6
64QAM 4/4	2 x 2 MIMO	10.4	25.9	43.2	86.4	172.8

Table 4: Uplink peak bit rates

Modulation coding		Peak bit rate per sub-carrier/bandwidth				
		72/1.4 MHz	180/3.0 MHz	300/5.0 MHz	600/10 MHz	1200/20 MHz
QPSK 1/2	Single stream	0.9	2.2	3.6	7.2	14.4
16QAM 1/2	Single stream	1.7	4.3	7.2	14.4	28.8
16QAM 3/4	Single stream	2.6	6.5	10.8	21.6	43.2

16QAM 4/4	Single stream	3.5	8.6	14.4	28.8	57.6
64QAM 3/4	Single stream	3.9	9.7	16.2	32.4	64.8
64QAM 4/4	Single stream	5.2	13.0	21.6	43.2	86.4

Apart from the high peak data rates performance, LTE also provides improved latency in the user experience. For example, LTE users can expect a 50 ms delay to set up the first connection and 5 ms latency in one way afterwards with 3.5G networks on account of all IP and much flatter LTE architecture [Motorola10]. Therefore, the LTE network reacts from the requests such as browsing, media playing, net meeting and online gaming almost instantaneously like a fixed-line broadband connection.

5. Summary

In this paper, we have taken a glance at LTE background motivations, primary adopted technologies and DL/UL specifications in order to gain a general knowledge of LTE in the first stage. Then, we have taken a close look at the major technical parts of LTE, for instance, LTE architecture, OFDMA, SC-FDMA, MIMO, TDD and FDD so that we could further understand the detailed contents, i.e. what consists of LTE flat architecture, what principles of LTE OFDMA and SC-FDMA schemes are, the similarities and differences between OFDMA and SC-FDMA as well as FDD/TDD duplex schemes. Finally, we also have examined the main end user application performance such as DL/UL peak data rates and low latency in real world. It is obvious that LTE makes a lot of innovations in terms of technology for the purposes of data rates and other performances as discussed above. Its peak throughputs have already exceeded what can be achieved by HSPA+. Moreover, LTE has obtained low cost per bit for a competitive service, enlarged the UL range and fulfilled the need for power-efficient device transmission.

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7. Acronyms

3G	the 3 rd generation
4G	the 4 th generation
3GPP	3 rd Generation Partnership Project
CDMA	Code Division Multiple Access
CN	Core Network
DFT	Discrete Fourier Transform
DL	Downlink
EDGE	Enhanced Data rates for GSM Evolution
eNB	eNodeB (Enhanced Node B)
EvDO	Evolution Data Only
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
IDFT	Inverse DFT
IFFT	Inverse FFT
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
OFDMA	Orthogonal Frequency Division Multiplex Access
PDCP	Packet Data Control Protocol
PDN GW	Packet Data Network Gateway
PHY	Physical Layer
QAM	Quadrature amplitude modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RFT	Radio Front End
RLC	Radio Link Control
SC-FDMA	Single Carrier- Frequency Division Multiplex Access
SGW	Serving Gateway
SISO	Single-Input and Single-Output
TDD	Time Division Duplexing
TD-SCDMA	Division- Synchronous Code Division Multiple Access
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication Service
WiMAX	Worldwide Interoperability for Microwave Access