CHANNEL ESTIMATION IN UPLINK OF LONG TERM EVOLUTION

Swati Nagle

Department of Electronics and Communication Engineering
National Institute of Technology Rourkela

Channel Estimation in Uplink of Long Term Evolution

A thesis submitted in partial fulfilment of the requirement for the degree of

Master of Technology

In

Electronics and Communication Engineering
Specialization: Communication and Networks

Swati Nagle
Roll No. 214EC5178

Under the supervision of
Prof. Poonam Singh

Department of Electronics and Communication Engineering,
National Institute of Technology Rourkela,
Odisha, 769008, India, May 2016

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENIGINEERING, NATIONAL INSTITUTE OFTECHNOLOGY, ROURKELA, ODISHA-769008

Certificate of Examination

This is to certify the thesis titled, **Channel Estimation in Uplink of Long Term Evolution** submitted by **Ms. Swati Nagle** bearing Roll No. 214EC5178 in partial fulfillment of the requirements for the award of the degree of Master of Technology in Electronics and Communication Engineering with specialization **Communication and Networks** during the session 2015-2016 at National Institute of Technology Rourkela is an original research work carried out under my supervision and guidance.

Place- NIT Rourkela

Date-

Prof. Poonam Singh

Associate Professor, Dept. of Electronics and Communication Engineering, NIT Rourkela, Odisha-769008

Department of Mining Engineering
National Institute of Technology Rourkela

Prof. Poonam Singh
Associate Professor

May, 2016

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This is to certify that the work presented in the dissertation entitled ***Channel estimation in Uplink of Long Term Evolution*** submitted by ***Swati Nagle***, Roll Number ***214EC5178***, is a record of original research carried out by him under our supervision and guidance in partial fulfillment of the requirements of the degree of ***Master of technology*** in ***Electronics and Communication Engineering***. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Prof. Poonam Singh
Associate Professor

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING, NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA, ODISHA-769008

Declaration

I certify that,

1. The work done in this thesis is original and completed by me under the guidance of my supervisor.
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Acknowledgement

Completion of this project is one of the greatest achievement of my career. This work would not have been possible without the help of many people who constantly supported me for which I am grateful to them.

With profound respects and significant admiration, I avail this chance to express my profound feeling of gratitude and obligation to **Prof. Poonam Singh**, Department of Electronics and Communication Engineering, NIT Rourkela for their significant guidance and support. I am profoundly obliged for the profitable discussions at every phase of the project. I consider it as my good fortune to have got an opportunity to work with such wonderful personalities.

I want to express my sincere gratitude to Prof. K.K. Mahapatra, HOD, Department of Electronics and Communication Engineering for creating an environment for study and research. Sincere thanks to Prof. S.K.Patra, Prof. S.K.Behera, Prof. S.Meher, Prof. S.K.Das, Prof. L.P.Roy, Asst. Prof. S.Maiti, Asst. Prof S.Deshmukh, Asst. Prof. A.K.Sahoo, Asst. Prof. S.Hiremath and Asst. Prof A.K.Swain for helping me learn and for their constant encouragement. I want to thank all faculty members and staff of the Department of Electronics and Communication Engineering, NIT Rourkela for their generous help.

I am especially indebted to my family for their constant love and guidance in every step of my life.I would like to make special mention of the selfless support and guidance I received from my classmates for their endless companionship and help. They made my stay at NIT, Rourkela pleasant.

Swati Nagle

Abstract

Long Term Evolution is considered to be the fastest spreading communication standard in the world. To live up to the increasing demands of higher data rates day by day and higher multimedia services, the existing UMTS system was further upgraded to LTE. To meet their requirements novel technologies are employed in the downlink as well as uplink like Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier- Frequency Division Multiple Access (SC-FDMA).

For the receiver to perform properly it should be able to recover the transmitted data accurately and this is done through channel estimation. Channel Estimation in LTE engages Coherent Detection where a prior knowledge of the channel is required, often known as Channel State Information (CSI). This thesis aims at studying the channel estimation methods used in LTE and evaluate their performance in various multipath models specified by ITU like Pedestrian and Vehicular. The most commonly used channel estimation algorithms are Least Square (LS) and Minimum Mean Square error (MMSE) algorithms.

The performance of these estimators are evaluated in both uplink as well as Downlink in terms of the Bit Error Rate (BER). It was evaluated for OFDMA and then for SC-FDMA, further the performance was assessed in SC-FDMA at first without subcarrier Mapping and after that with subcarrier mapping schemes like Interleaved SC-FDMA (IFDMA) and Localized SC-FDMA (lFDMA). It was found from the results that the MMSE estimator performs better than the LS estimator in both the environments. And the IFDMA has a lower PAPR than LFDMA but LFDMA has a better BER performance.

Keywords: LTE; Channel Estimation; IFDMA; LFDMA; Least Square (LS); MMSE; SC-FDMA.

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Acronym Used in Thesis:

ACI	Adjacent Channel Interference
AMPS	Advanced Mobile Phone System
BER	Bit Error Rate
CCDF	Complimentary Cumulative Distribution Function
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CSI	Channel State Information
CSR	Cell-Specific Reference Signals
CSI-RS	Channel-State Information Reference Signal
DFDMA	Distributed Frequency Division Multiple Access
DFT	Discrete Fourier Transform
DM-RS	Demodulation Reference Signal
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
GPRS	General Packet Radio Service
GSM	Global System for Mobile communication
HSPA.	High Speed Packet Access
HSS	Home Subscriber Server
IDFT	Inverse Discrete Fourier Transform
IFDMA	Interleaved Frequency Division Multiple Access
ISI	Inter Symbol Interference
ITU	International Telecommunication Union

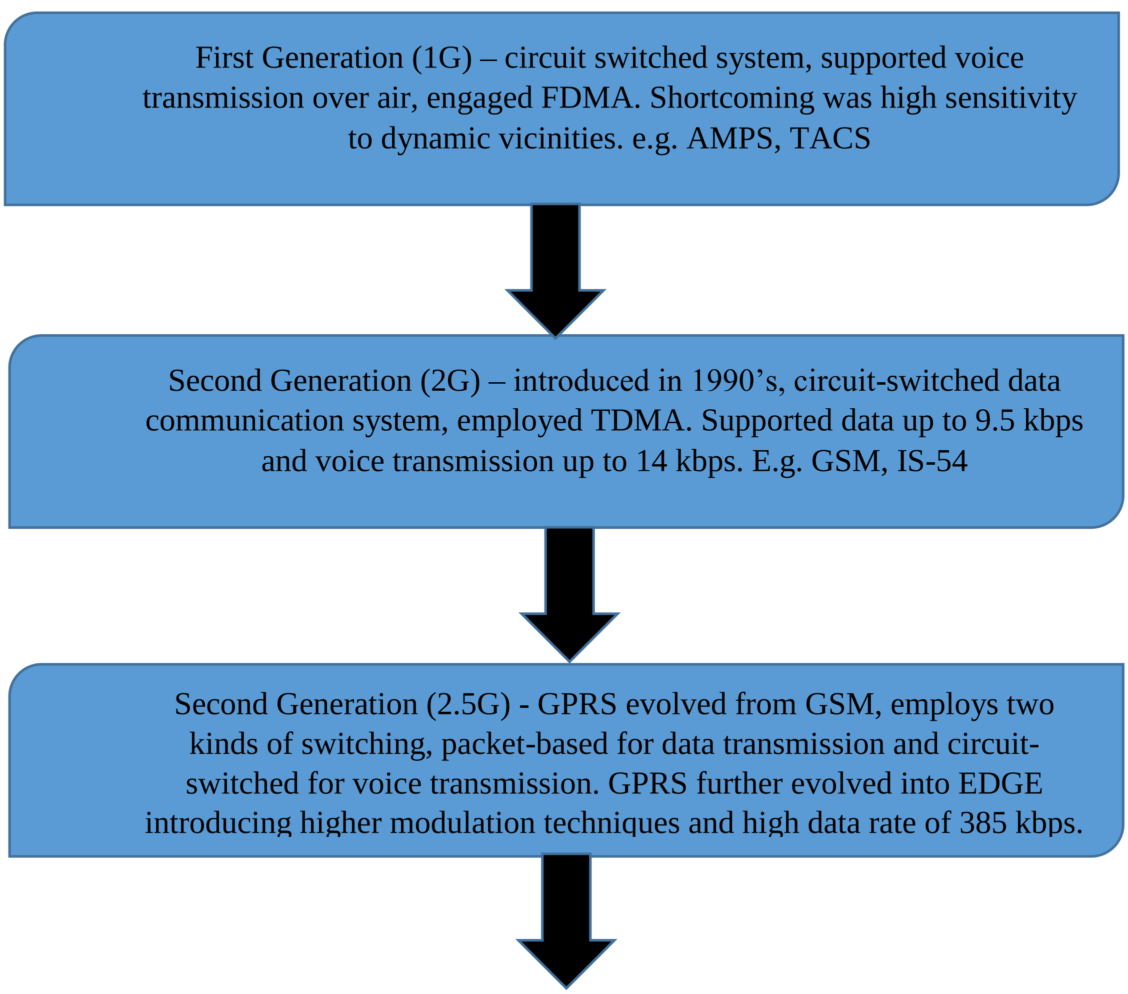
LFDMA	Localized Frequency Division Multiple Access
LTE	Long Term Evolution
MME	Mobility Management Entity
MMSE	Minimum Mean Square error
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak-to-average Power ratio
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SC-FDMA	Single Carrier- Frequency Division Multiple Access
TACS	Total Access Communication System
TDD	Time Division Duplex
UMTS	Universal Mobile Telecommunication system

CHAPTER-1

INTRODUCTION

The previous two decades have seen a fast development in the quantity of subcarrier and mind-boggling progression in the innovation of cell correspondence. From basic, all-circuit switched, simple first-eras frameworks with restricted voice service capabilities, constrained mobility, and small capacity to the fourth generation (4G) systems with fundamentally expanded capacity, all-IP executions that offer an assortment of media administrations. With the expanding interest in mixed media benefits, the radio access innovations keep on advancing with faster pace towards the up and coming generations of wireless networks.

1.1 Evolution of Wireless Standards:



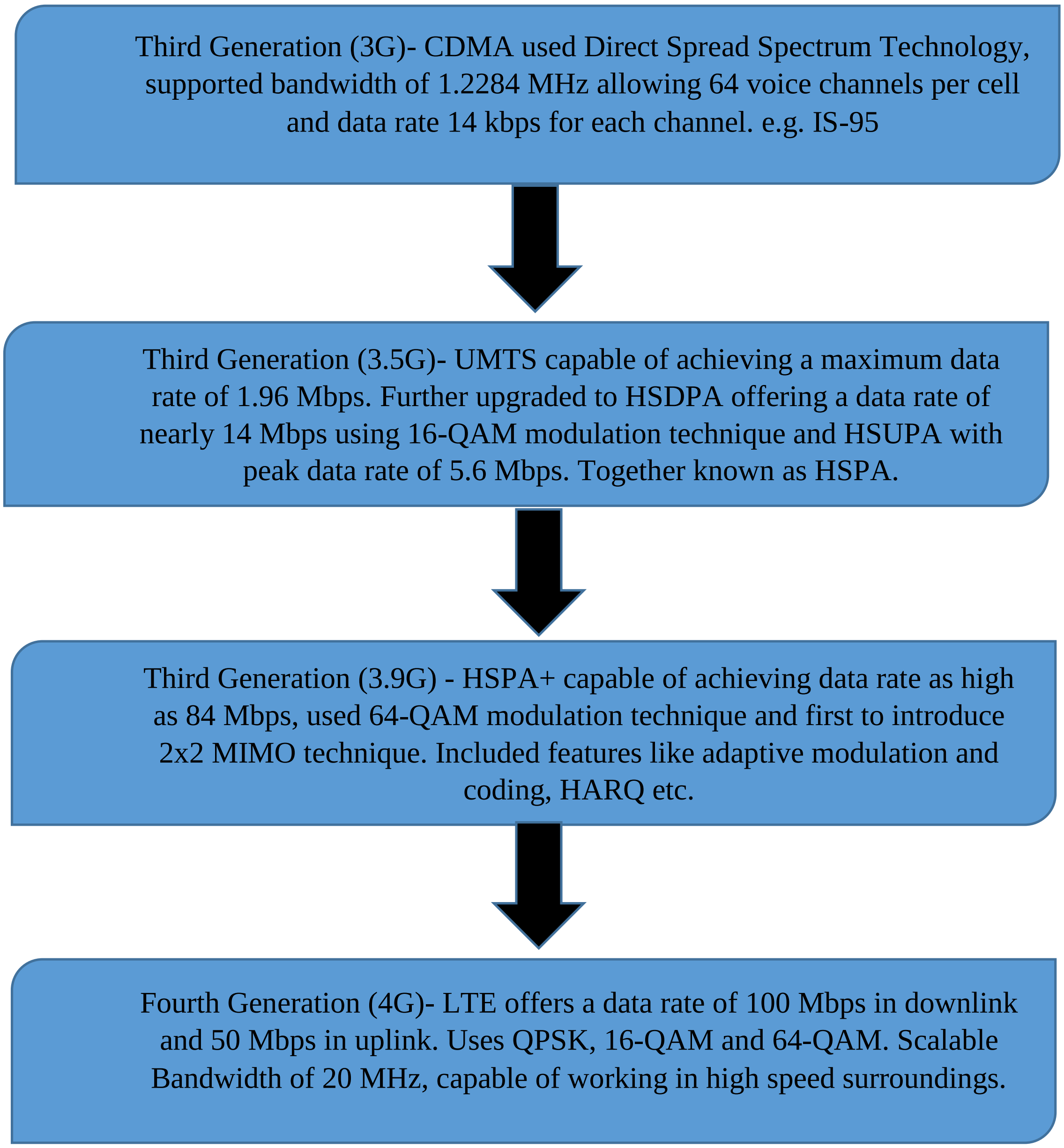


Figure 0-1.1 Evolution of Wireless Standards

1.2 Introduction to 3GPP LTE:

Long Term Evolution, usually known as 4G is the new standard for next generation mobile communication system. LTE is nothing but a brand name given to the efforts of 3GPP towards development of 4G technology. It was initiated in the year 2004. The LTE 'Release 8'[2] is commonly considered to be the fourth generation but many hold the assertion that LTE 'Release 10' i.e. LTE-Advanced is the true evolution step towards 4G, while LTE 'Release 8' is considered 3.9G[1]

Some of the requirements that serve as motivation for the development of LTE includes requirement of a simple network with open interface at a low cost, efficient use of existing and new frequency bands, decrease in cost per bit, better user experience and the decrease in terminal complexity allowing a fair amount of reduction in power consumption. After all these goals, further expectations were raised for LTE like, reduction in latency of packets, improved spectral efficiency more than the HSPA, about 3 to 4 times better in downlink and 2 to 3 times in the uplink. One of the most attractive features of LTE is its scalable bandwidth which allows LTE to be deployed flexibly among other existing systems.

Other than the scalable bandwidth, the most associated feature of LTE is its speed. Peak data rates for uplink and downlink of LTE are shown in Table 1.2 for a channel bandwidth of 20 MHz these high Peak data rates in the Downlink and Uplink are achieved using Technologies like OFDMA and SC-FDMA. Table shows the peak data rate for a scenario where single antenna is employed as well as when multiple antennas are used.

One of the main improvisations in LTE that the existing mobile communications don't possess is the use of MIMO technology from the beginning. This leads to a cohesive methodology applied to the advanced antenna technology that adds MIMO to a legacy system like HSPA. Moreover, LTE aims at low mobility applications ranging from 0 to 15 Km/h where the uppermost performance is observed. The system also supports applications within the mobility range of 15 to 120 Km/h and functional support in the range 120 to 350 Km/h. the support for speeds from 350 to 500 Km/h is under consideration.

DOWNLINK PEAK DATA RATES			
Antenna Configurations	SISO	2x2 MIMO	4x4 MIMO
Peak Data Rates Mbps	100	170.8	325.4

UPLINK PEAK DATA RATES			
Modulation	QPSK	16-QAM	64-QAM
Peak Data Rates Mbps	50	57	86

Table 1.1: Peak Data Rates in Downlink and Uplink of LTE

1.3 Why OFDMA and SC-FDMA??

The main reasons why LTE employs OFDMA and its single- carrier equivalent SC-FDMA specified in [3] includes

- Its robust nature against the multipath fading
- Less complexity required for implementation
- High spectral efficiency
- Flexibility of transmission bandwidths
- Support to cutting-edge features like MIMO [4], frequency selective scheduling etc.

OFDMA is nothing but a multicarrier scheme, that divides the data being transmitted on a wideband in the frequency domain into a number of narrowband orthogonal sub-channels referred to as subcarriers. The frequency-selective fading channel can be embodied as an assembly flat-fading narrowband subcarriers when the frequency spacing is very less. This enables the OFDMA to estimate the channel frequency response with ease by transmitting reference symbols. This in turn provides the ability to recover an accurate estimate using low-complexity frequency domain equalizer.

Despite being an efficient transmission scheme OFDMA suffers with large variations in the instantaneous transmission power. This leads to the reduction of efficiency in the power amplifiers and greater power consumption at the mobile terminal. In case of uplink transmission, designing a high performance complex power amplifiers is a challenging and difficult task. To overcome this difficulty, a variant of OFDMA known as Single-Carrier Frequency Division Multiple Access is used, where a DFT-based precoding is performed combined with OFDM resulting in substantially lower power as compared to OFDMA making it suitable for use in uplink.

1.4 Literature Review:

In order to fulfill the exponentially growing needs of the wireless network services, a high speed data access communication standard has been developed known as Long Term Evolution. To achieve its goal it employs technologies like OFDMA and SC-FDMA in the uplink and downlink respectively. The performance gain of LTE over other systems was its ability to estimate the Channel State Information (CSI) accurately and efficiently, which is necessary for every communication system [5]. This is done through Channel estimation which is a crucial part of modern communication systems for the receiver to perform efficiently. The most commonly used among several channel estimation techniques are LS and MMSE as specified in [8] and implemented using basic channel estimation model [6]. There are various ways in which Channel estimation can be performed like Parametric Model, Blind or Pilot Based, adaptive or Non-adaptive. But among them mostly pilot-based estimation is used where known reference signals are sent along with the data to estimate the channel at the receiver [7]. The LS estimator is easy to implement but it suffers with large MSE while MMSE is a more efficient estimator its implementation is a bit complex. These estimators can also be used in the uplink but same transmission technique is not used in uplink as downlink. SC-FDMA is used because of its lower PAPR along with its ability to provide higher throughput and lower BER than the OFDMA. It also uses different types of subcarrier mapping schemes like LFDMA and IFDMA which has lower PAPR [9]. These subcarrier mappings improve the PAPR performance of the system and also the performance of the estimators.

1.5 Thesis Objective:

In this thesis, we investigate a critical part of the LTE-based receivers that contributes significantly in achieving the LTE requirements for an acceptable overall performance this part is the channel estimation. Accurate channel estimates at the receiver have a major impression on the whole system performance. Part of the system design requires identifying estimators that make their implementation at the receivers practical while maintaining a satisfactory Bit Error Rate (BER) performance. Realizing estimators in LTE-based receivers that can sustain high performance in high-mobility environments is a growing research field, where tradeoffs between complexity and BER have to be considered [4].

The main objective of this thesis is to investigate and assess channel estimation techniques such as Minimum Mean Square Error and Least Square in various multipath models specified by ITU [25] such as Pedestrian and Vehicular models in which the channel is varying and come forth with a channel estimation technique that is efficient and suitable in all the conditions.

1.6 Thesis Outline:

The thesis consists of five chapters:

- Chapter 1 discusses the evolution of the wireless standards and introduction to LTE along with why the respective schemes are used in LTE. And also the motivation of the thesis.
- Chapter 2 gives an overview of the physical layer of Long Term Evolution. It discusses the network architecture of LTE and its requirements.
- Chapter 3, describes the physical layer processing in uplink and downlink of LTE and gives description of the OFDMA and SC-FDMA technology along with the description of channel models used.

- Chapter 4 describes the approach to channel estimation and the channel estimation techniques like Least Square and Minimum Mean Square Error and evaluates their performance in various multipath models.
- Chapter 5 concludes the thesis and proposes future work that can be done in order to continue the investigation.

CHAPTER -2

AN OVERVIEW OF LTE

2.1 Requirements of LTE:

The evolved UMTS terrestrial radio access (E-UTRA) supports a number of other applications along with mobile internet like HTTP, FTP, and VoIP etc. LTE has been designed to fulfill the requirements of higher data rate and low air link access latency needs of the existing and emerging application. The bandwidth of LTE is much greater than the earlier existing technologies allowing it to provide higher throughput and peak data rates in uplink as well as downlink. This enables the service providers to adapt their services according to the available spectrum or it is capable of starting with a limited spectrum for lower cost services and then later escalating the spectrum for additional capacity.

A summary of LTE system requirements is shown in Table 2.1 [1]. Beyond these metrics, LTE targets at diminishing intricacy and intake of power and cost-effective migration from UMTS systems.

Metric	Requirement
Peak Data Rate	Downlink: 100 Mbps (5bps/Hz) ; Uplink: 50 Mbps (2.5 bps/Hz) within a 20 MHz uplink spectrum allocation
Mobility	Optimized for low mobile speed from 0 to 15 km/h, can also support mobility ranging between between 15 and 120 km/h should be supported with high performance. Mobility across the cellular network shall be maintained at speeds from 120 to 350 km/h (or even up to 500 km/h depending on the frequency band)

Control-plane latency	Transition time of less than 100 ms from camped state to active state, transition time of less than 50 ms between dormant state and active state
User-plane latency	Less than 5ms in unload condition (i.e., single user with single data stream) for small IP packets
Average user throughput/MHz	Downlink: three to four times Release 6 HSDPA Uplink: two to three times Release 6 enhanced uplink
Coverage	Throughput, spectrum efficiency, and mobility targets should be met for 5 km cells, and with a slight degradation for 30 km cells. Cells range up to 100 km should not be precluded
Spectrum efficiency (bits/sc/Hz/site)	Downlink: three to four times Release 6 HSDPA Uplink: two to three times Release 6 enhanced uplink

Table 2.1: Requirements of Long Term Evolution

2.2 Overall Network Architecture

LTE network architecture comprises of the following key components

- The User Equipment (UE)
- The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)
- The Evolved Packet Core (EPC)

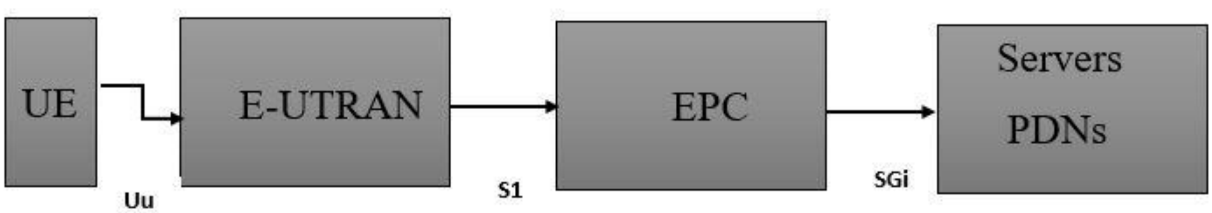


Figure 0-1.1: Basic Block Diagram of Network Architecture of LTE

2.2.1 The User Equipment (UE):

The User Equipment [21] is a device used for the purpose of communication by the end-user. It transmits information to the base station eNodeB or receive information from the base station. It can be either a mobile equipment or a laptop equipped with mobile broadband. The functions of

UE includes mobility management, call control, session management and identity management. All the calls are initiated by the UE and it is considered to be the terminal device in a network.

2.2.2 E-UTRAN (the Access Network):

The E-UTRAN [12] in LTE is given the task of handling radio communication between user equipment and Evolved Packet Core. It consists of only one component which is a base station that controls the mobiles in one or more cells, referred to as eNodeB or eNB. The base station that communicates with a user equipment is known as the Serving eNodeB of that equipment. In LTE only one mobile equipment and one base station communicates at a time. E-UTRAN has two main functions:

- The eNodeB is responsible for sending and reception of radio signals to all the mobiles employing analog and digital signal processing functions of LTE air interface.
- The eNodeB also controls the low level operations of user equipment such as sending them signaling messages like handover commands.

The interface between eNodeB and EPC is the S1 interface and eNodeB can also be allied to a nearby station through X2 interface mainly used for the signaling packets forwarded all through handover. An eNodeB employed to deliver cell coverage within the home is called Home eNodeB. The Home eNodeB is part of a Closed Subscriber Group (CSG) which can be accessed by only those mobile equipment having a USIM belonging to the CSG.

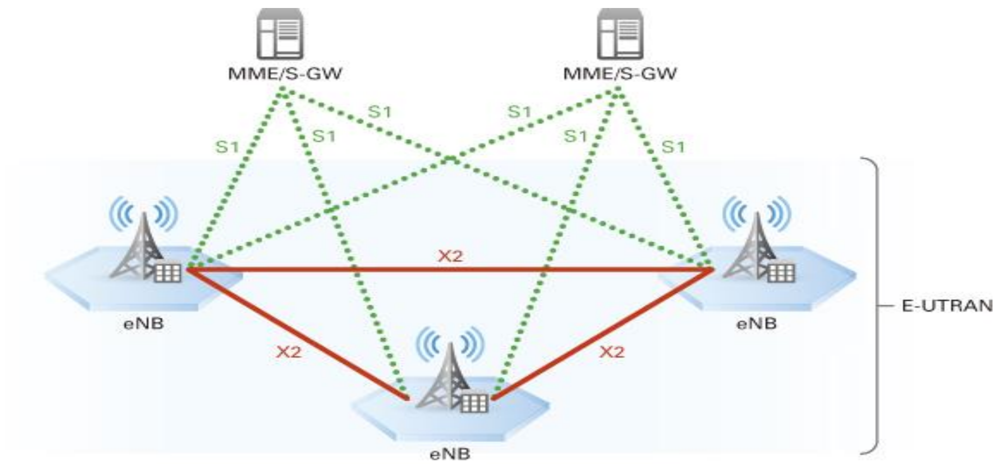


Figure2.2 Internal Architecture of E-UTRAN

2.2.3 The Evolved Packet Core (EPC) [the core network]:

The EPC is responsible for communicating with the data network in the outside world like, internet, private corporate networks or IP Multimedia system.

The EPC comprises of the following components:

- **Home Subscriber Server (HSS):** This behaves as the central data base containing information about all the networks' operator subscribers. This component has been carried forward from the existing GSM and UMTS networks.
- **The Packet Data Networks (PDN) Gateway (P-GW):** this component is used to communicate with the outside world or we can say Packet data networks through SG_i interface. Access Point Name (APN) is used to identify each Packet Data Network. The PDN-Gateway serves the same purpose as the GPRS Support Node (GGSN) and the serving GPRS Support Node (SGSN) within UMTS and GSM networks.

- **Serving Gateway (S-GW):** this component is used to transfer data from the base station to the PDN gateway and behaves as router.
- **Mobility Management Entity (MME):** High Level operations of the mobile equipment is controlled by this component using signaling messages and Home Subscriber Server.
- **Policy Control and Charging Rules Function:** This component is accountable for policy-control and decision-control, it also controls the flow based charging functionalities in the policy control enforcement function residing in P-GW.

The interface through which the serving and PDN Gateway connect is known as S5/S8 interface. S5 interface is used when both devices are in the same network while S8 interface is used when the devices are in different networks.

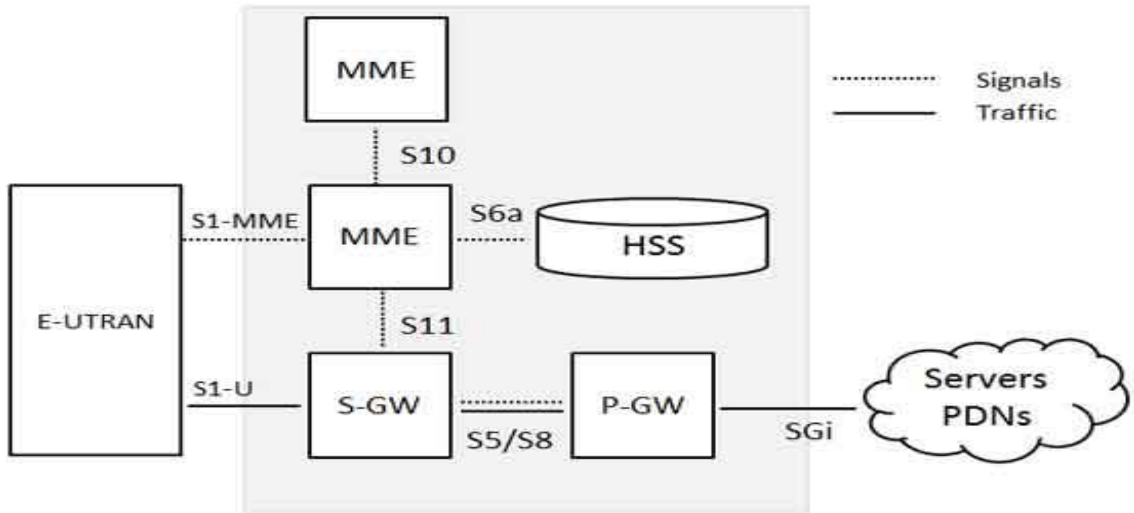


Figure 2.3: Internal Architecture of EPC

2.3 LTE Physical Layer:

2.3.1 Duplex Modes

One of the crucial factors in radio communication is the way in which the communication is carried out in both directions and maintained. The need to maintain data transmission in both the directions simultaneously places many limitations on the respective scheme that can be used to control this flow of transmission. The LTE supports two types of duplex modes

- Frequency Division Duplex mode (FDD)
- Time Division Duplex mode (TDD)

Frequency Division Duplex (FDD)

This duplexing scheme is employed when two alternative RF carriers are used for simultaneous transmission in the uplink and downlink or when the transmit or receive are frequency division multiplexed in frequency domain. The FDD duplex mode broadcasts information in both the directions simultaneously using different frequencies. These two frequency have a large difference between them or we can say frequency offset.

A large frequency offset is needed in order to prevent the interference of transmitted signal at the receiver side for the proper performance of FDD scheme. Another crucial concern with this scheme is Receiver Blocking that often requires using high selective filters. The base station as well as the user equipments must be equipped with these filter so as to ensure the sufficient isolation of the transmitted signal without desensitizing the receiver. Placing these filters in the user terminal is a challenging task and requires high implementation cost. In FDD the re-allocation of spectrum in order to change the capacity of uplink and downlink is not possible as there is a large difference between both the frequencies.

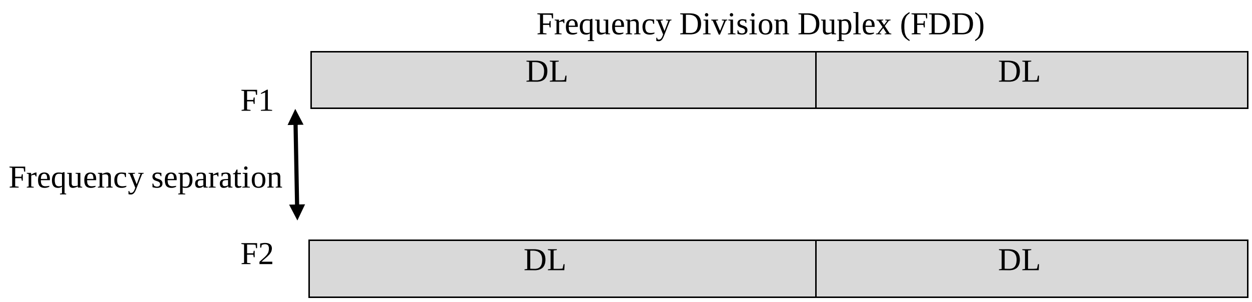


Figure 2.4: Frequency division Duplex Mode of transmission

Time Division Duplex (TDD)

In this duplex scheme the uplink and downlink transmissions take place at different time instants but may have a common frequency. In other words, we can say that both the transmissions are time multiplexed and does not occur concurrently. In TDD the transmission and reception must be separated by a time difference known as Guard Interval or Guard Time. This guard interval must be adequate in order to allow the signals coming from remote transmitter to reach before another transmission is started and before the receiver is shut down. The guard interval will comprise of two key elements:

- A time allowance for the propagation delay for any transmission from a remote transmitter to arrive at the receiver.
- A time allowance for the transceiver to switch from the receive to transmit mode.

The advantage of using this scheme includes the relative ease with which the capacity can be changed by varying the number of time slots allocated in both courses.

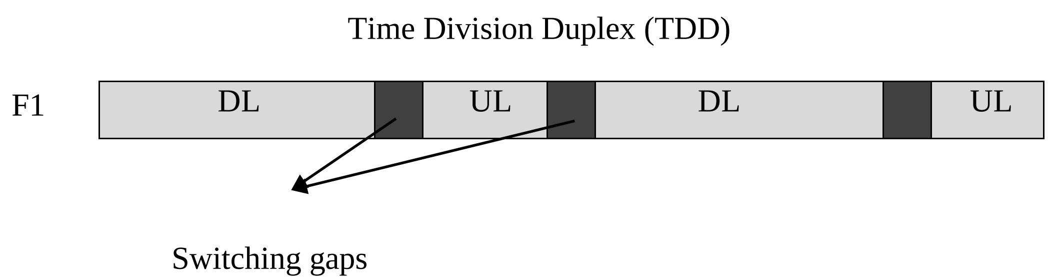


Figure 2.5: Time Division Duplex Mode of Transmission

2.3.2 Frame structure:

Downlink and Uplink transmissions in the LTE are organized in the form of radio frames of duration 10ms. It supports two types of radio frame structures

- Type-1 Frame Structure
- Type-2 Frame Structure

Type-1 Frame Structure:

Frequency Division Duplex (FDD) scheme engages this type of frame structure, for both FDD modes i.e. half duplex and full duplex. Each radio frame of 10ms duration is divided into 10 equal parts of 1ms duration each. This subdivided frame of 1ms further comprises of two slots of equal size of 0.5ms each. In FDD 10 subframes are accessible for downlink transmission as well as uplink transmission in each radio frame. The uplink and the downlink transmissions are carried out at different frequencies i.e. there is a separation between them in frequency domain. The downlink and uplink Transmission Time Interval (TTI) is 1ms.

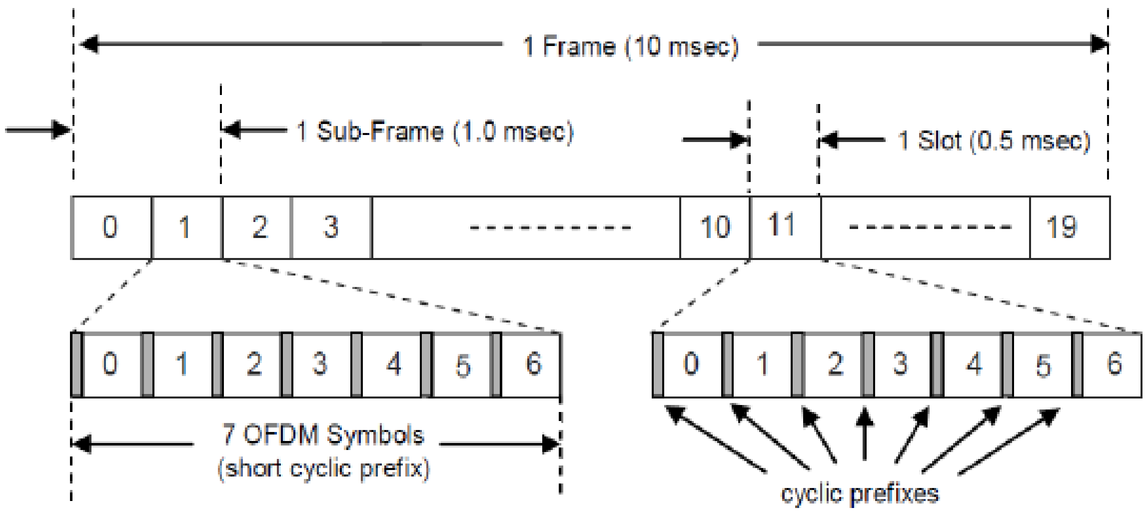


Figure 2.6: Type-1 Frame Structure

Type-2 Frame structure:

Time Division Duplex Scheme (TDD) uses this type of frame structure. Each radio frame of 10 ms is divided into two half-frames of 5ms each. There are a total of 8 slots in each half frame with the following three special fields:

- downlink pilot time slot (DwPTS)
- guard period (GP)
- Uplink pilot time slot (UpPTS).

The length of DwPTS and UpPTS is configurable subject to the total length of DwPTS, GP, and UpPTS being equal to 1ms. The first subframe and the sixth subframe in configuration with 5ms of switching-point periodicity contains DwPTS, GP, and UpPTS. The sixth subframe in configuration with 10ms of switching-point periodicity consists of only DwPTS. All other subframes have two slots of equal size. The GP is held in reserve for downlink to uplink transition in the TDD systems, Other subframes or fields are allotted for either downlink or uplink transmission as given in Table 2.2.

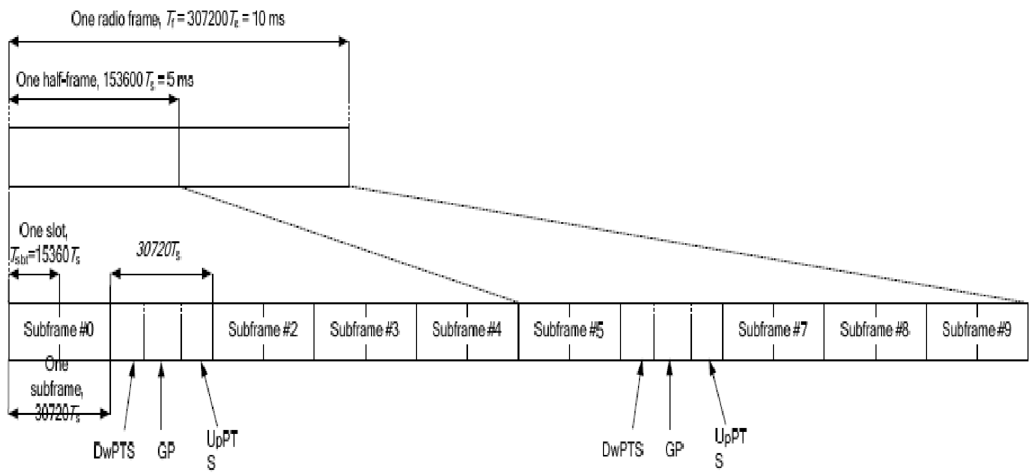


Figure 2.7: Type-2 Frame Structure

UPLINK-DOWNLINK CONFIGURATION	DOWNLINK TO UPLINK SWITCH PERIODICITY	SUBFRAME NUMBER									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Table 2.2 : Permissible uplink/downlink configurations in frame structure Type 2

2.3.3 Time and Frequency Synchronization:

In LTE there is need of time and frequency synchronization during initialization, to serve this purpose synchronization signals are transmitted along with every radio frame. The UE synchronizes to the OFDM symbols, subframes, half-frames and radio frames through the use of these synchronization signals. Two types of synchronization signals are used in LTE:

- Primary Synchronization signal: this is used to obtain the boundaries of slots, subframes and half-frame. It also makes the cell identity available within the CIG.

- Secondary Synchronization signal: this is used to obtain the boundaries of radio frame. So, this makes the UE capable of identifying CIG which can lie within a range of 0 to 167.

Each 0th and 5th subframe of every radio frame are used to transmit the synchronization signals. They are occupying the center frequency 1.08 MHz of the radio channel in the frequency domain.

The 0th and 10th slot of every radio frame are used to transmit the primary and the secondary synchronization signals. The signals occupy the last two symbols within these slots. The primary synchronization signal is transmitted in the last symbols of the 0th and 10th and secondary synchronization is transmitted one before the last symbols of 0th and 10th slot. The center frequency of 1.08 MHz of the radio channel is held reserve for the primary and secondary synchronization signals.

2.3.4 Physical Resource Blocks:

The basic LTE downlink physical resource can be represented in time-frequency grid, as shown in Figure below:

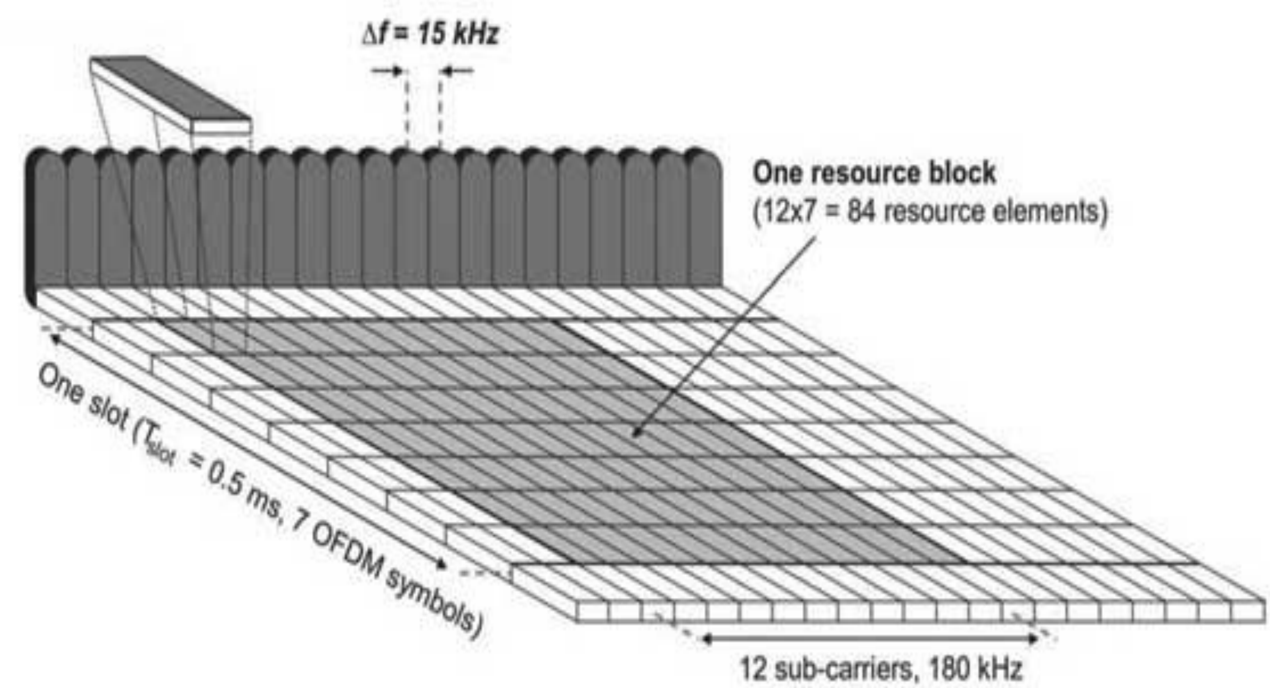


Figure 2.8: Illustration of OFDM in LTE using Physical Resource Blocks

The smallest time-frequency unit used for transmission in LTE is knowns as a Resource Element and it is defined as one subcarrier over one OFDM symbol. An assembly of 12 subcarriers together continuous in frequency over one time slot results in one Physical Resource Block (PRB). A PRB is a 2D region comprising of one slot in time domain and 180 KHz in frequency domain (12 x 15 KHz = 180 KHz). PRB's are the units of transmission allocated in LTE. The size of a resource block is 0.5ms in time domain and 180 KHz in the frequency domain as discussed earlier and the OFDM symbols in LTE are grouped together into resource blocks. Each TTI consists of 2 time slots (T-slots) of 0.5ms each.

For carrying out the transmission each user in LTE is allocated some resource blocks in time-frequency grid. The more number of resource blocks allocated to a particular user and higher the modulation scheme used, the higher will be the Bit Rate obtained. How many and which of the resource blocks a user acquires at a given time depends upon the scheduling mechanisms used in Time and frequency domains. The number of resource block corresponding to each Bandwidth [15-16] is given in table 2.3

Number of Resource blocks	Bandwidth (MHz)
6	1.4
15	3
25	5
50	10
75	15
100	20

Table 2.3: Illustration of number of resource blocks of the corresponding Bandwidth

2.3.5 Modulation and Coding:

The downlink or uplink of LTE supports many baseband modulation schemes like QPSK, 16-QAM and 64-QAM. Similar to UTRA the channel coding scheme is turbo coding for transport blocks in LTE. The coding scheme has a coding rate of R = 1/3 along with two 8-state constituent encoders and a contention-free quadratic permutation polynomial (QPP) turbo code internal interleaver [16].After encoding of all the information bits is done by taking the tail bits from shift register feedback, the Trellis termination is performed. Succeeding the encoding of all information bits the tail bits are padded.

Before performing turbo coding, the transport blocks are segmented into aligned segments comprising of eight states with a maximum information block size of 6144 bits. 24-Bit CRC is used for error detection.

2.3.6 Reference signals:

In an OFDM system to make the estimation of multipath channel simple and easier, Coherent detection is employed that uses Reference symbols (or pilot symbols). The pilot symbols makes an estimate of the channel frequency response available at the pilot locations over the time-frequency grid. Now, by using Interpolation techniques the estimate of the channel can be recovered at other time-frequency locations. There are numerous types of downlink and uplink reference signals specified in LTE.

Downlink Reference Signal:

The channel estimation functionality required to equalize and demodulate data or control information is fully supported by Downlink Reference Signals. They also play a very crucial role in CSI measurement required for channel quality feedback. There are five types of reference signals specified in LTE

- Cell-Specific Reference Signals (CSR)
- Demodulation Reference Signal (DM-RS, otherwise known as UE-specific reference signal)
- Channel-State Information Reference Signal (CSI-RS),
- MBSFN Reference signals, and
- Positioning Reference signals.

Cell-Specific Reference Signals:

In the frequency domain, the CSRs are located in every downlink subframe and resource block and thus covering the entire bandwidth. For performing the channel estimation through coherent detection of downlink physical channels, the cell-specific reference signals are used during initial stage of cell selection. They may be used by the terminal to get the Channel State Information (CSI). The received signal strength from the CSRs sent from antenna port 0 forms the basis for the measurements relating to the scheduling and handover functions. In the time-frequency grid, in order to prevent the overlapping of CSR's in the adjacent cells, a frequency shift is applied to the mapping locations of CSR's. when the CSR symbols are located in the antenna of the same cell they are time multiplexed.

UE-Specific Reference Signals:

A UE must perform a separate channel estimation for each antenna port for the purpose of determining the channel characteristics from an antenna port. So, to estimate the respective channel another set of suitable reference signals are defined for the antenna port. These reference signals are known as UE-specific Reference Signals or DM-RSs . They are used in those transmission modes of LTE where CSRs cannot be used. Within a pair of resource blocks we have 12 reference symbols when only one DM-RS is used. There is a key difference between the CSR and UE specific reference signals. When the above two signals are used on 2 antenna ports, all the 12 reference symbols are transmitted on both the antenna ports . The solution to diminish the interference between them is by generating a mutually orthogonal pattern for each set of reference symbols.

CSI Reference Signals:

These were first introduced in Release-10 of LTE for the newly proposed multi-user MIMO techniques. This new technique requires some prior knowledge of the channel state information at the base station so that the system can adjust according to the radio channel conditions dynamically to optimize the performance. For cases where the number of antennas is between 4 and 8, CSI

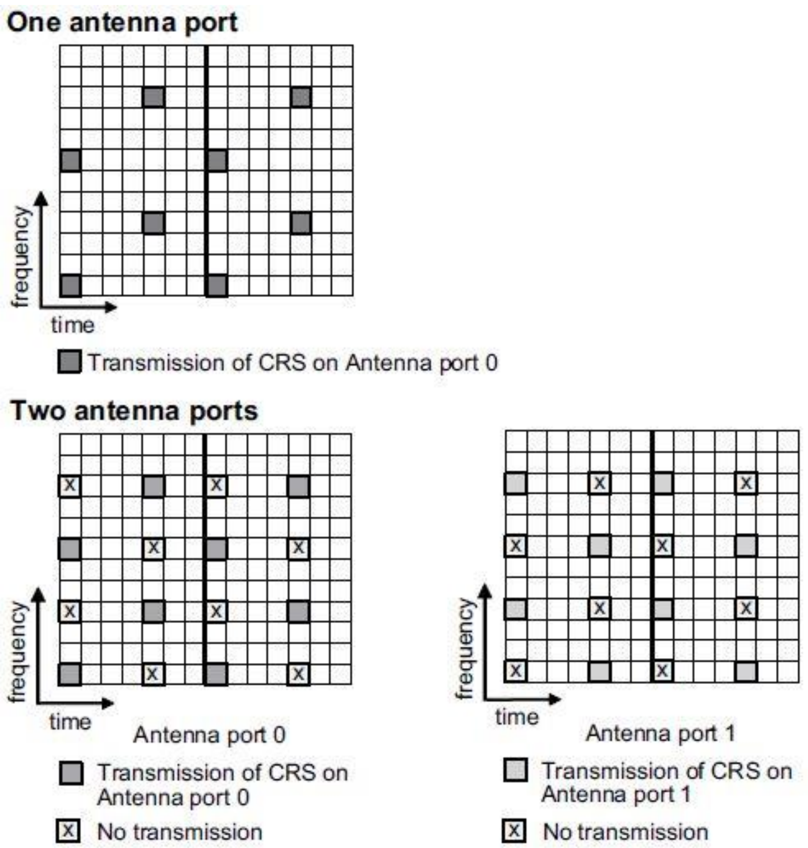


Figure 2.9: Reference symbols position in the Resource grid for one antenna and two antenna port

reference signals were designed to permit the channel state measurement and reporting by UE for up to 8 downlink transmit antennas to aid eNodeB pre-coding functions in transmission mode 9. While the DM-RS supports channel estimation functionality, on the other hand a CSI-RS acquires Channel State Information. To decrease the overhead occurring from having two types of reference signal within the resource grid, the temporal resolution of CSI-RSs is made low.

Uplink Reference Signal:

Demodulation Reference Signals and Sounding Reference Signals are the two types of reference signals specified by LTE for Uplink transmission. Both uplink reference signals are based on Zadoff–Chu sequences. From the different cyclic shift parameters of the basesequence with the purpose of generating different Reference Signals for different UEs.

Demodulation Reference Signals:

The UE transmits the Demodulation reference signals as a fragment of the uplink resource grid. The base station receiver uses these signals to demodulate and equalize data and control information. In case of PUSCH, the DSR signals are located on every fourth OFDM symbol of each subframe in 0.5ms slot and spread over the entire resource block. In PUCCH, the location of the DRS depends upon the format of the control channel.

Sounding Reference Signals:

The sounding reference signals are transmitted as a fragment of the uplink resource grid to facilitate the base station in estimating the channel response at various frequencies.. The channel state estimates obtained are utilized for channel-dependent scheduling. So, we can say that the scheduler is capable of allocating user data to those segments of uplink bandwidth where channel responses are favorable. When downlink and uplink channels are reciprocal or identical, like in TDD the SRS transmissions can serve in other applications such as timing estimation and control of downlink channel conditions.

CHAPTER-3

PROCESSING IN LTE

The LTE downlink is based on OFDM, a very appealing transmission scheme due to its robustness against the multipath fading channel. Other motivations include high spectral efficiency, low –complexity implementation and provision for flexible transmission bandwidths. Since, one of our objectives is to analyze the channel estimation techniques in LTE downlink it is necessary to have an understanding of the OFDM technique. In the following chapter, the characteristics of LTE more relevant to the channel estimation will be presented along with the system model of the LTE Downlink.

3.1 Downlink Transmission in LTE:

OFDM is a transmission scheme that transforms a wide band of frequency selective channel into a set of non-selective narrow-band sub-carriers that are orthogonal to each other, making it robust against the large delay spread channels preserving its orthogonality in the frequency domain. And the introduction of cyclic redundancy concept at the transmitter further reduces the complexity to FFT processing. The narrow-band sub-carriers are modulated by orthogonal waveforms thereby allowing the spectrum to be overlapped and thus resulting in high spectral efficiency. In practice, the best way of implementing these orthogonal subcarriers is Discrete Fourier Transform (DFT) and Inverse Discrete Fourier Transform (IDFT) processes which can be implemented proficiently using Fast Fourier Transform and Inverse Fast Fourier Transform.

In OFDM, the transmitted data undergoes N-Point IFFT so as to generate the samples to be applied for the summation, resulting in the sum of N orthogonal subcarrier signals as shown in figure 3.1.

At the receiver side, N-Point FFT of the received symbols is performed giving the noisy version of the transmitted signal. Because of the subcarriers being constrained to a finite length T, the spectrum of an OFDM signal can be considered as the sum of frequency-shifted sinc functions in the frequency domain where spacing between subsequent carriers is 1/T. Since, each subcarrier has a finite time duration foe each symbol, the OFDM signal can suffer from out-of-band radiation responsible for Adjacent Channel Interference (ACI). To mitigate this effect, a guard band is placed at outer subcarriers, generally known as Virtual Subcarriers (VCs) to reduce the around the frequency band. And to diminish the effect of Inter Symbol Interference (ISI), a guard interval is introduced among the time domain called the Cyclic Prefix (CP).

The function of the transmitter in OFDM is to map the data bits onto a sequence of PSK or QAM symbols that are transformed into N parallel streams. Different subcarriers carry out the conversion of each of the N symbols from serial to parallel form.

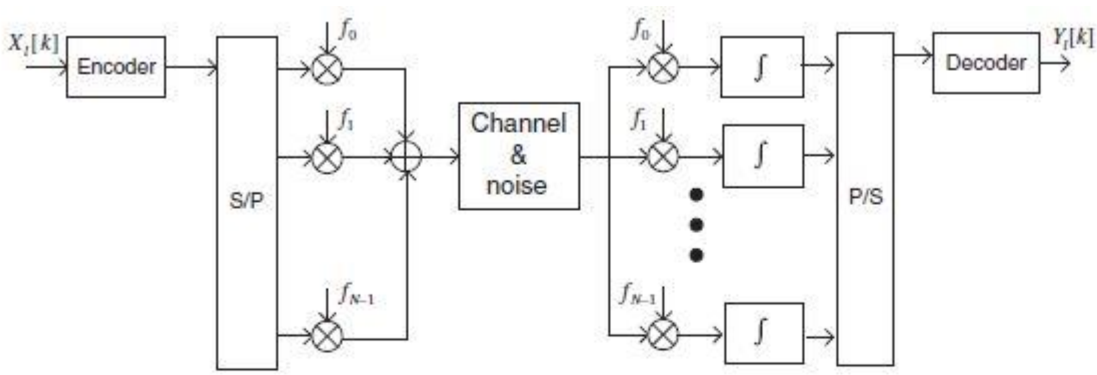


Figure 3.1: Outline of OFDM transmission Scheme

Let $X_k(l)$ denote the k^{th} transmitter symbol at the l^{th} subcarrier, where k = 0,1,2…..∞ and l= 0,1……. N-1. Because of the conversion of symbols from serial to parallel the time taken to transmit N symbols is extended to NT_s which forms only one OFDM symbol with a duration of t_{symb} (i.e. t_{symb} = NT_s).

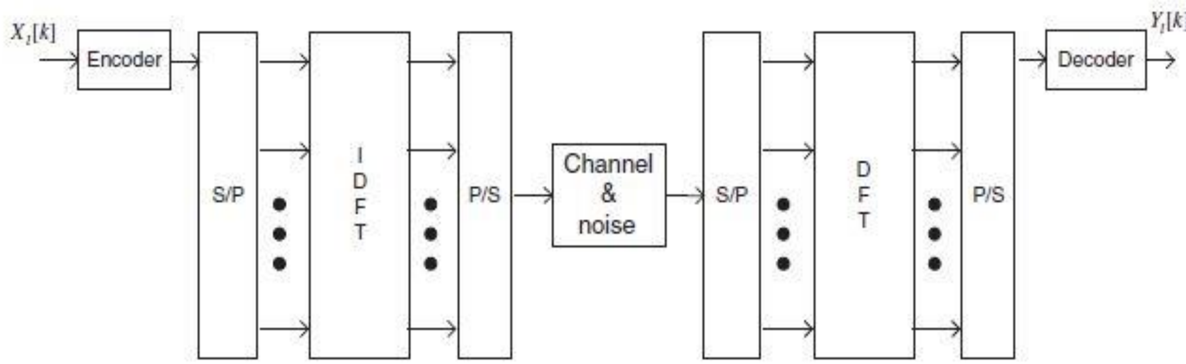


Figure 3.2: OFDM implementation using IFFT/FFT

Let $\psi_{k,l}(t)$ be the OFDM symbol at the l^{th} subcarrier, which is given as

$$\psi_{k,l}(t) = \begin{cases} e^{j2\pi f_l\,(t-kt_{symb})} & 0 < t < t_{symb} \\ 0 & elsewhere \end{cases}$$

In the continuous time domain the passband and baseband OFDM can be represented respectively as

$$x_k(t) = \text{Re} \left\{\frac{1}{t_{symb}} \sum_{k=0}^{\infty}(\sum_{k=0}^{N-1} X_k(l)\ \psi_{k,l}(t)\right\} \quad \dots\dots\dots \quad (3.2)$$

And

$$x_k(t) = \sum_{i=0}^{\infty} \sum_{k=0}^{N-1} X_k(l)\, e^{j2\pi f_l(t-kt_{symb})} \quad \dots\dots\dots \quad (3.3)$$

The sampling of the baseband OFDM signal takes place at t = $kt_{symb} + nT_s$ with $T_s = t_{symb}/N$ and $f_l = l/t_{symb}$ to yield the corresponding discrete time OFDM symbol as

$$x_k[n] = \sum_{k=0}^{N-1} X_k(l)\ e^{j2\pi kn/N} \qquad \text{for n = 0, 1, 2, ….. N-1………} \quad (3.4)$$

This equation represents the N-point IDFT of the PSK or QAM symbols and can be calculated efficiently by using IFFT algorithm.

Now, at the receiver side the received OFDM symbol is taken into consideration

$$Y_k(t) = \sum_{l=0}^{N-1} X_k(l)\, e^{j2\pi f_l(t-\, kt_{symb})} \qquad kt_{symb} < t \ \leq kt_{symb} + nT_s$$

From which transmitted symbols can be reconstructed by orthogonality among the subcarriers as follows:

$$y_k[l] = \frac{1}{t_{symb}} \int_{-\infty}^{\infty} Y_k(t)\, e^{-j2\pi l f_l\left(t-kt_{symb}\right)}\, dt$$

$$= \frac{1}{t_{symb}} \int_{-\infty}^{\infty} \left(\sum_{i=0}^{N-1} X_l(i)\, e^{j2\pi f_i(t-kt_{symb})} \right.$$

$$= \sum_{i=0}^{N-1} X_l(i) \left\{ \frac{1}{t_{symb}} \int_{0}^{t_{symb}} e^{j2\pi(f_i - f_k)(t-kt_{symb})}\, dt \right\}$$

$$= X_k(l)$$

The above equation is the N-Point DFT of the received signal and can be calculated proficiently by a DFT algorithm. Thereby, proving that the OFDM transmission scheme is one of the most efficient way of implementing multi-carrier transmission by using IFFT and FFT algorithms. The spectrum of the OFDM is as shown in figure 3.3.

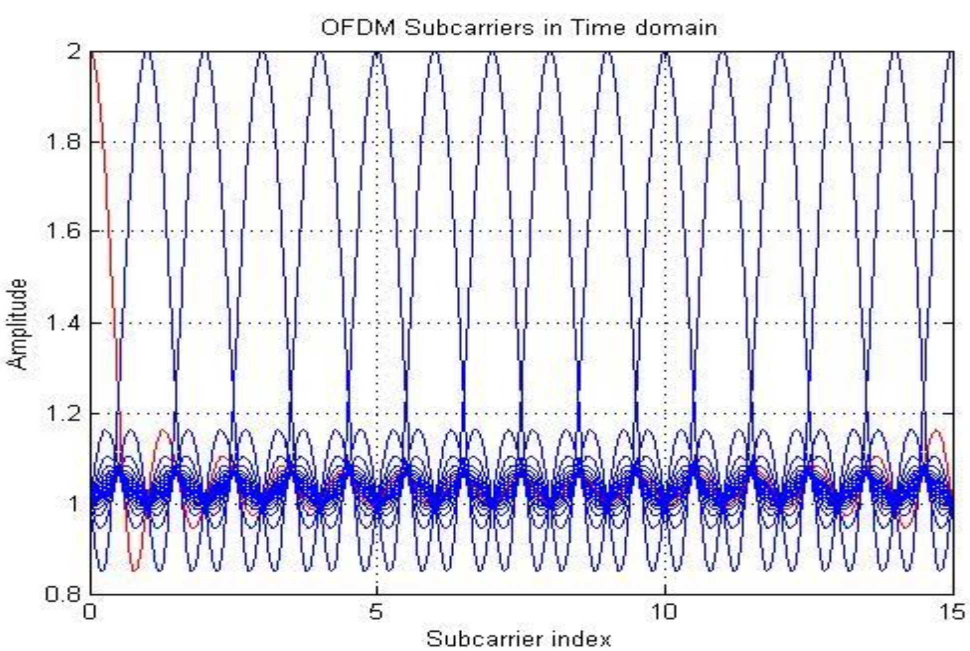


Figure 3.3: Orthogonal Subcarriers of OFDM in the time domain

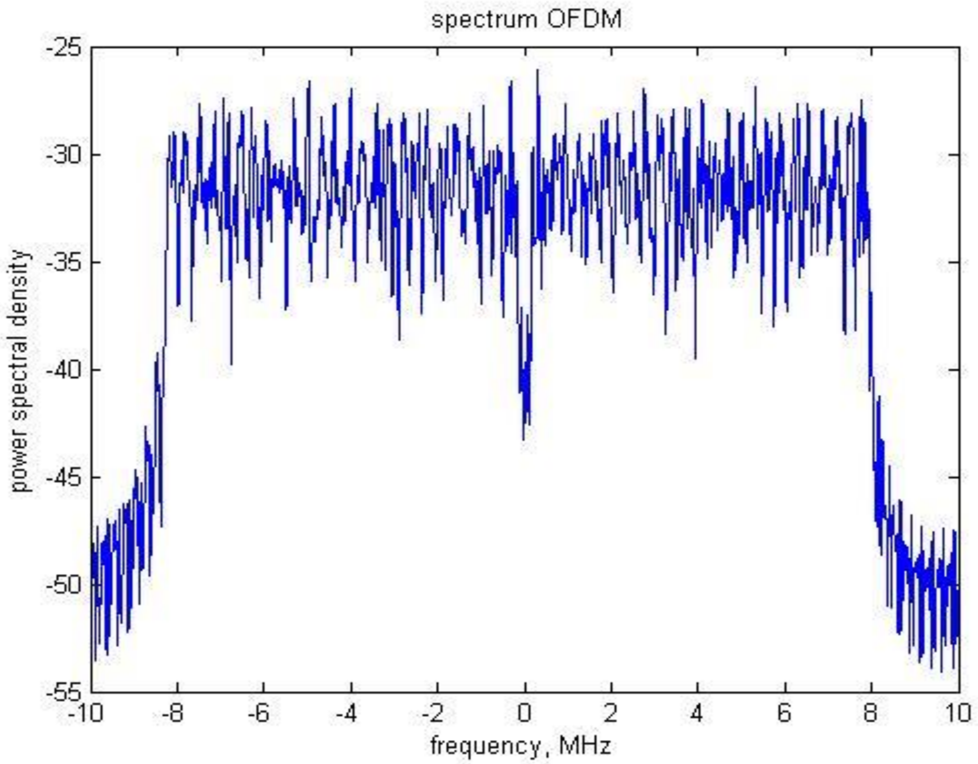


Figure 3.3: Spectrum of an OFDM signal

3.1.1 Cyclic Prefix (CP):

Practically, the Inter Symbol Interference (ISI) between the OFDM symbols is caused due to the linear distortions like multipath delays, resulting in the loss of orthogonality in the subcarriers and an effect similar to Adjacent Channel Interference (ACI).Cyclic prefix (CP) concept was introduced to counter this problem [18]. When the delay spread is within the useful length of an OFDM symbol, the influence of the ISI is trivial, although it depends on the order of modulation implemented by the subcarriers. The most effective and simple way of eliminating the problem of ISI is to increase the duration of OFDM symbol in such a way that it is larger than the delay spread and however when the delay spread is large that requires a large no. of subcarriers.

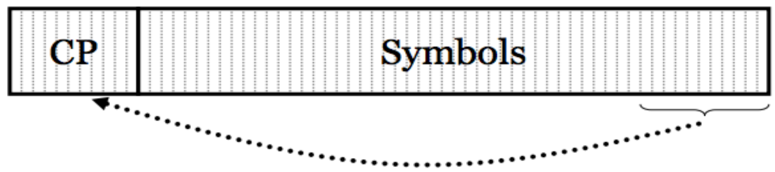


Figure 3.4: Cyclic Prefix

It is necessary that the duration of cyclic prefix is as long as the significant part of the channel impulse response experienced by the transmitted signal. In this way there is a two-fold advantage of the CP

- It acts as guard interval between the subsequent OFDM symbols hence, the ISI is eliminated.
- And the linear convolution of the CP with CIR results in a cyclic convolution, the latter performed in the time domain corresponds to scalar multiplication in the frequency domain and therefore this preserves the orthogonality of the subcarriers and prevents ISI.

But the benefits of CP does not come without a cost. As the length of the CP increases the power required to transmit the signal also increases. Because of the insertion of CP there is a loss in the signal to noise ratio and this loss in SNR is given as

$$SNR_{loss} = -10 \log_{10} 1 - \frac{T_{CP}}{T}$$

Where T_{CP} ⟶ duration of the cyclic prefix

T_s ⟶ duration of the symbol

T = T_{CP} + T_s , is the duration of the transmitted symbol.

3.1.1 LTE System Downlink Model:

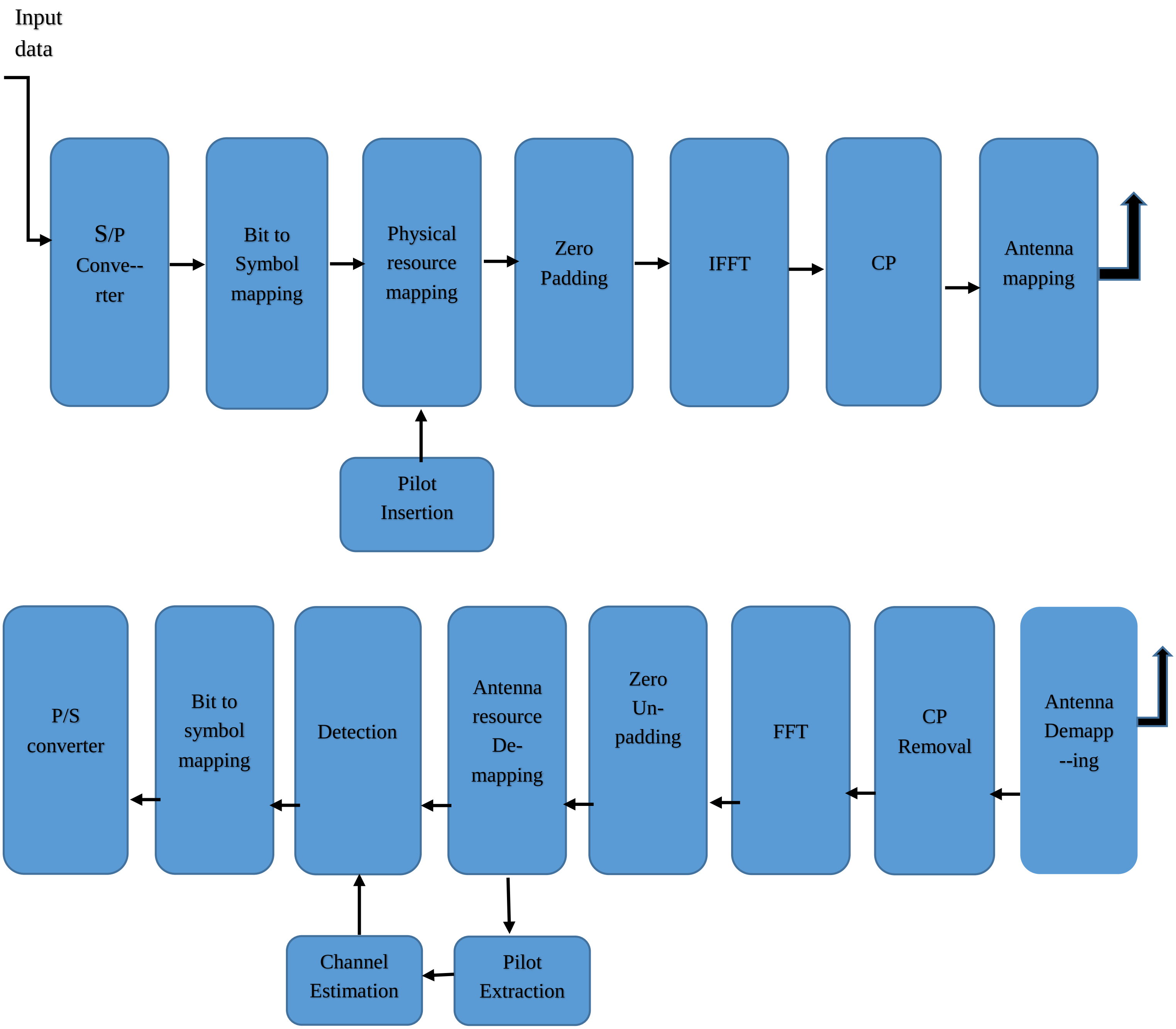


Figure 3.5: Basic LTE Downlink Model

In practice, the OFDM symbols in an LTE Downlink system are generated by performing certain manipulations on the serial input information bits as shown in Figure 3.5.

Firstly all the input information bits are converted into a number of parallel data streams by using a Serial to Parallel Converter, which are then mapped onto different subcarriers in the form of symbols by using various modulation techniques such as QPSK, 16-QAM and 64-QAM defined in [18]. Mapping the symbols using different constellations is a way of allocating a sinusoid with a unique amplitude or phase to the input information bits. These higher order modulation techniques are required to attain high data rates and bandwidth efficiency.

Then according to the Frame Structure of LTE Downlink as defined in chapter 2, all the constellation symbols and pilot symbols are mapped on the OFDM resource grid. The pilot symbols can be arranged in different manners on the resource grid for the purpose of channel estimation as documented in [19]. As the transmission bandwidth is much lesser than the sampling rate, the length of the signal spectrum is increased by adding a number of zeros at the end of the signal spectrum and this is known as Zero Padding. Now IFFT is performed on these zero padded signals to generate OFDM symbols. To sustain the orthogonality of corresponding time domain waveforms, a frequency gap must be maintained. In the frequency domain these signals overlap, therefore utilizing all the bandwidth available in an effective way. IFFT is an effectual means of generating the OFDM modulated symbols and reducing the complexity of transmitter. After this the CP is inserted to prevent ISI before the transmission.

On the receiver side, operations opposite to that of the transmitter is performed to obtain estimates of multipath channel to recover information as accurately as possible. At first, Cyclic prefixes are removed and then FFT is performed in order to obtain the OFDM modulated symbols and thereby transforming the signal into frequency domain. To obtain the transmitted data, channel estimation (described in chapter 4) is done in the detection stage where, pilot symbols are extracted from each subframe and the recovered constellation symbols are de-mapped into binary input bits and then converted from parallel to serial form giving the recovered information bits.

3.2 Uplink Transmission in LTE:

The 3GPP has espoused the Single-Carrier Frequency Division Multiple Access (SC-FDMA) scheme for the uplink transmission in LTE [29]. It is nothing but an improved form of OFDMA that has some advantages over the OFDMA technology like low PAPR, hence reducing the energy required for transmission and the ability to eliminate ISI. With all of the above advantages it also accede to the property of robustness against the multipath signal propagation. This makes it a suitable technique for uplink transmission.

SC-FDMA is also known as Discrete Fourier Transform (DFT) pre-coded OFDMA, as before going through the modulation process all the time domain input data bits undergo a DFT thus converting them to frequency domain. However, the use of word 'single-carrier' in this technique is not evident always. It is named in this way, as unlike standard OFDM where a subcarrier carries information about only one symbol, SC-FDMA assigns the data symbol to be carried to a group of subcarriers transmitted simultaneously. In other words, the group of subcarriers that carry each data symbol can be viewed as one frequency band carrying data sequentially in a standard FDMA.

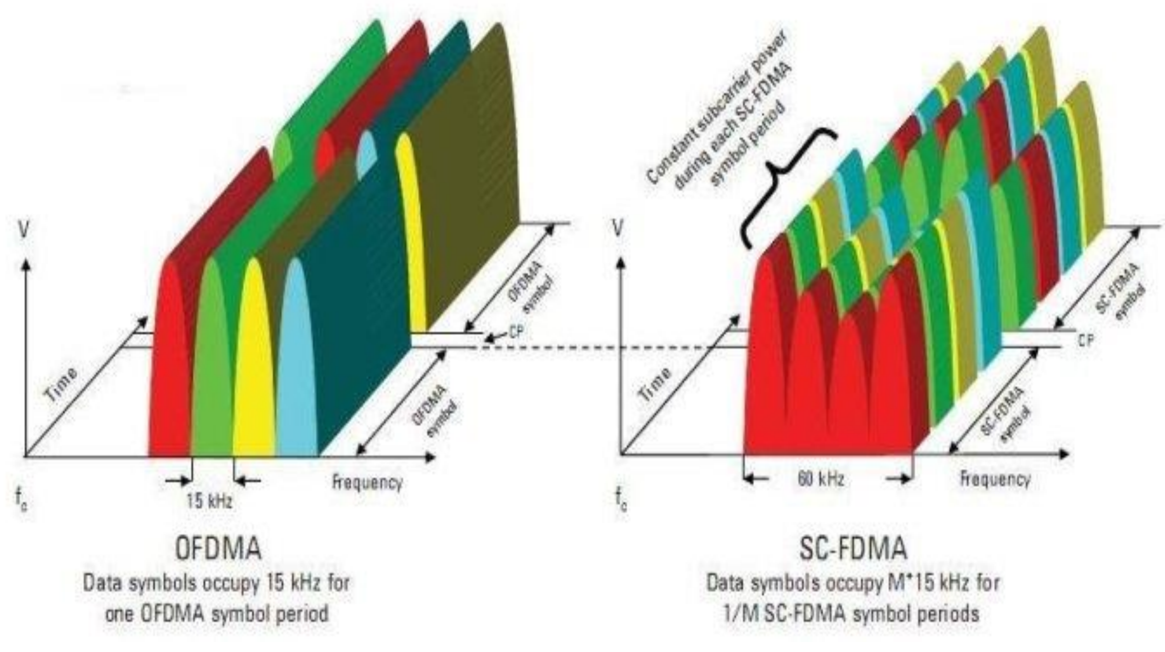


Figure 3.6: Subcarrier Mapping in OFDMA and SC-FDMA

One of the main drawbacks of OFDMA that holds it back is its high Peak-to-Average Power Ratio (PAPR). Since, all the modulated subcarriers sum up to give the transmit signal, high peaks are unavoidable because many subcarriers have the same phase for some inputs. As a result a heavy affliction is imposed on the power amplifier of the transmitter which makes it unsuitable for uplink transmission and also its vulnerability to frequency offset, which are both shown below.

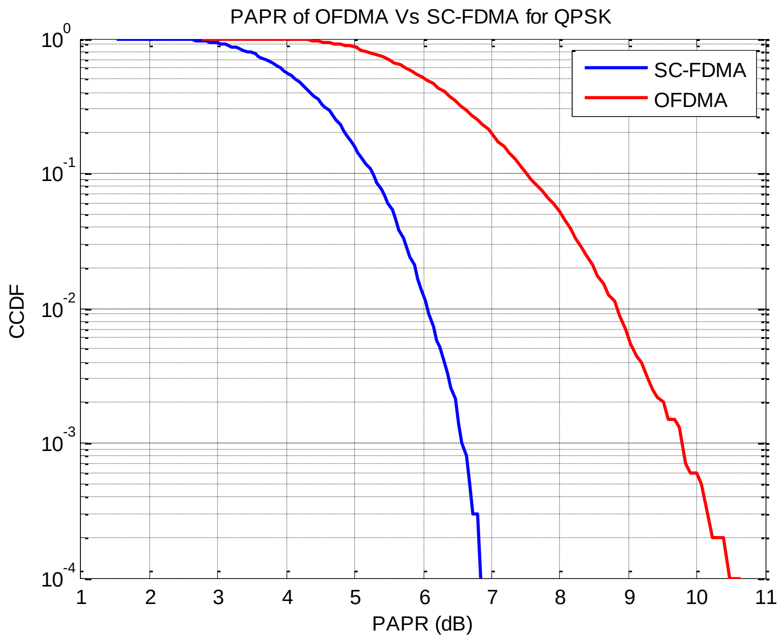


Figure 3.7: CCDF of PAPR for OFDMA Vs SC-FDMA using QPSK

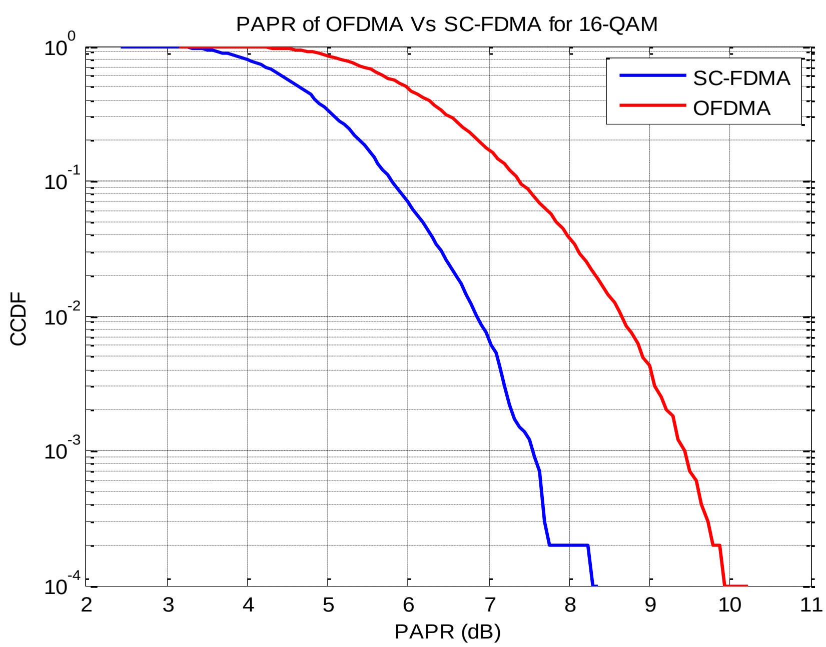


Figure 3.8: CCDF of PAPR for OFDMA Vs SC-FDMA using 16-QAM

3.2.1 LTE Uplink System Model:

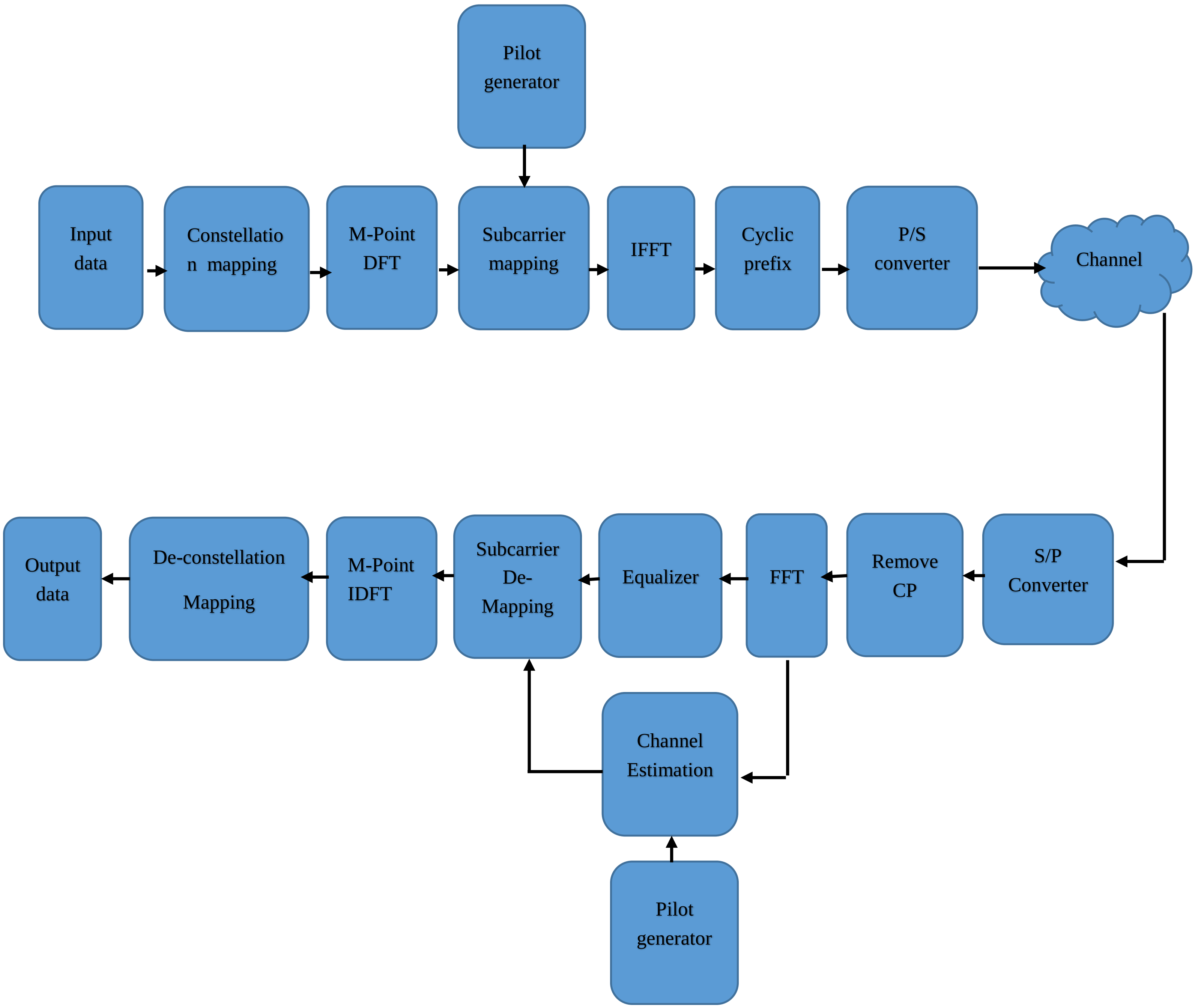


Figure 3.9: UPLINK MODEL OF LTE

The above block diagram depicts the Uplink system model used in LTE. Its structure is nearly similar to the OFDM transmission scheme except for one block i.e. DFT which is introduced before the sub-carrier mapping. A set of modulated symbols generated with the help of modulation techniques like QPSK, 16-QAM or 64-QAM is applied to the M-Point DFT block. This DFT produces M frequency domain symbols that are responsible for modulating M sub-carriers from N available orthogonal sub-carriers which are spreading over a bandwidth

$$B_{chann} = N\, f_{sub}\ \ Hz$$

Where f_{sub} is sub-carrier spacing. The Channel transmission rate is

$$R_{chann} = \frac{N}{M}\, R_{source} \quad \text{[Symbols/second]}$$

And the spreading factor is given as

$$\text{Q} = \frac{R_{chann}}{R_{source}} = \frac{N}{M}$$

The DFT process is then followed by Sub-carrier Mapping, also known as scheduling where each of the sub-carriers is assigned the complex output value as its amplitude which is further explained in section 3.4 below. After this the IFFT operation converts the frequency domain symbols into time domain. To prevent the ISI cyclic prefix (as described in section 3.1.1) is added to the end of each signal .The parallel to serial converter transforms the parallel time domain signals into an organized sequence for transmission.

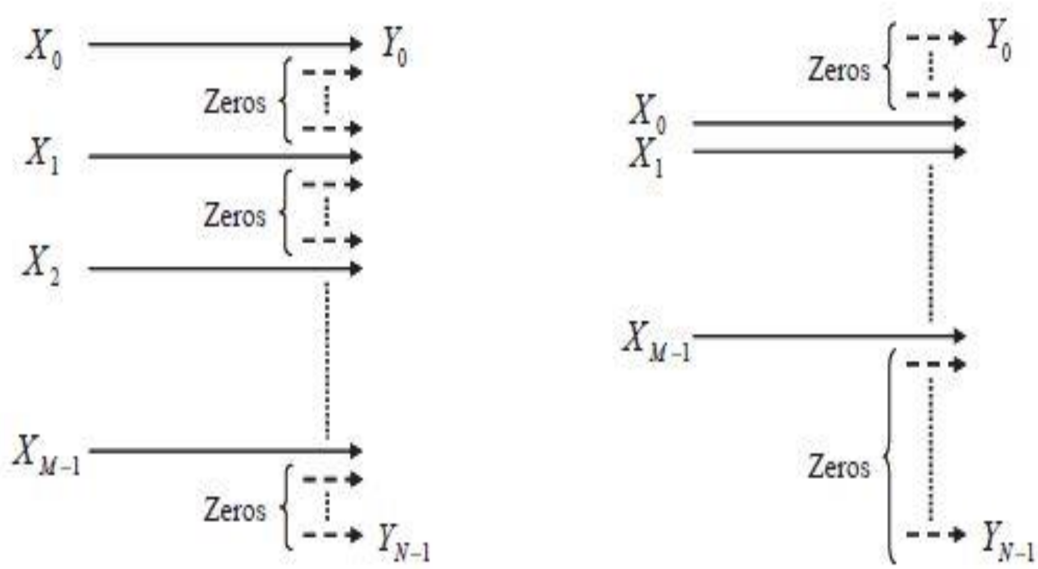
At the receiver first and foremost task is to remove the CP and then perform DFT to convert the time domain signals into frequency domain that may be equalized by dividing it point-by-point by an estimate of channel frequency response. Then the equalization is performed in order to compensate for the linear distortions caused by multipath propagation. ISI caused between two symbols is removed by frequency domain equalization. Then a IDFT is performed on the equalized symbols to transform them to time domain and constellation de-mapping is done to recover the input data. The SC-FDMA is an optimum transmission scheme from the point of view of performance as well as throughput because of the lower sensitivity to carrier frequency offset and lower complexity at the transmitter that benefitsthe mobile terminal in cellular uplink communications.

3.3 Subcarrier Mapping:

Subcarrier mapping is defined as the process of assigning frequency domain modulated symbols upon the available subcarriers. Two modes of sub-carrier mapping is defined

- Distributed Subcarrier Mapping
- Localized Subcarrier Mapping

In the distributed mode, each symbol is assigned to sub-carriers placed equidistant from each other spreading across the whole bandwidth. In the localized mode, the modulated symbols are assigned to adjacent sub-carriers. M out of N sub-carriers are assigned the complex modulated value and the rest $N - M$ subcarriers are assigned zero as its amplitude. The Localized mode of subcarrier mapping in SC-FDMA is referred to as Localized FDMA (LFDMA) and Distributed mode as Distributed FDMA (DFDMA). There is a special case of DFDMA in which there is equal distance between the occupied sub-carriers and is commonly known as Interleaved FDMA (IFDMA). This is a very efficient way of subcarrier mapping that does not require use of DFT and IDFT for modulating the signal in time domain at the transmitter. The only difference between DFDMA and IFDMA is that the in IFDMA the outputs are mapped to sub-carriers spread across the whole bandwidth and on DFDMA it is assigned to every several sub-carriers.



Distributed **Local**

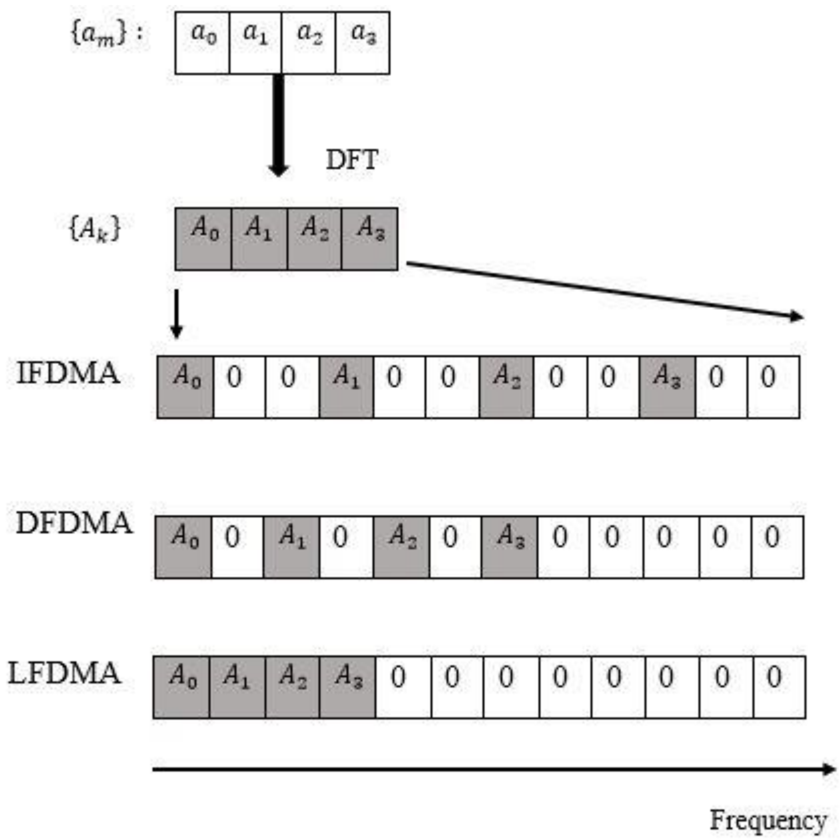


Figure 3.10: demonstration of different subcarrier mapping schemes

The above figure depicts the examples of frequency domain subcarrier mapping of the transmitted symbols for M= 4 symbols per block, N= 12 subcarriers and $Q = N/M$ = 3 terminals. In LFDMA, the modulated symbols occupy the subcarriers 0, 1, 2, 3:$Y_0 = A_0, Y_1 = A_1, Y_2 = A_2$, $Y_3 = A_3$ and $Y_i = 0$ for i ≠0,1,2,3. In DFDMA all the modulated symbols are placed over equidistant subcarriers, $Y_0 = A_0, Y_2 = A_1, Y_4 = A_2 , Y_6 = A_3$ and in IFDMA $Y_0 = A_0, Y_3 = A_1, Y_6 = A_2, Y_9 = A_3$.

The time domain representation of Interleaved SC-FDMA output symbols is depicted below. Let $m = N.q + n$ and M = Q.N where 0 $\leq q \leq Q - 1$ and 0 $\leq n \leq N - 1$. Then,

$$\tilde{a}_m \,(= \tilde{a}Nq + n) = \frac{1}{m} \sum_{l=0}^{M-1} \widetilde{A_l}\, e^{j2\pi \frac{m}{M} l} \qquad (3.4)$$

$$= \frac{1}{Q} \cdot \frac{1}{N} \sum_{k=0}^{N-1} A_k \, e^{j2\pi \frac{m}{M} k}$$

$$= \frac{1}{Q} \cdot \frac{1}{N} \sum_{k=0}^{N-1} A_k \, e^{j2\pi \frac{nq+N}{N} k}$$

$$\frac{1}{Q} \cdot \left(\frac{1}{N} \sum_{k=0}^{N-1} A_k \, e^{j2\pi \frac{n}{N} k} \right) = \frac{1}{Q} \, . x_n$$

Now the time domain representation of Localized SC-FDMA is given as follows.

Let $m = Q.n + q$ and M = Q.N where $0 \le q \le Q - 1$ and $0 \le n \le N - 1$. Then

$$\tilde{a}_m = \tilde{a}_{Q.n+q} = \frac{1}{m} \sum_{l=0}^{M-1} \widetilde{A_l} \, e^{j2\pi \frac{m}{M} l}$$

$$= \frac{1}{Q} \cdot \frac{1}{N} \sum_{l=0}^{N-1} A_l \, e^{j2\pi \frac{Q.n+q}{QN} l} \qquad (3.5)$$

If q=0 , then

$$\tilde{a}_m = \tilde{a}_{Q.n} = \frac{1}{Q} \cdot \frac{1}{N} \sum_{l=0}^{N-1} A_l \, e^{j2\pi \frac{Q.n}{QN} l}$$

$$= \frac{1}{Q} \cdot \frac{1}{N} \sum_{l=0}^{N-1} A_l \, e^{j2\pi \frac{n}{N} l} = \frac{1}{Q} \, . x_n \qquad (3.6)$$

If q ≠ 0, then

$$A_l = \sum_{p=0}^{N-1} a_p \, e^{-j2\pi frac \, pNl}$$

$$\tilde{a}_m = \tilde{a}_{Q.n+q}$$

$$= \frac{1}{Q} \left(1 - e^{j2\pi \frac{q}{Q}} \right) \cdot \frac{1}{N} \sum_{p=0}^{N-1} \frac{a_p}{1 - e^{j2\pi \left\{ \frac{n-p}{N} + \frac{q}{Q.n} \right\}}} \qquad (3.7)$$

From the above equations we can see that the most desired choice for subcarrier mapping is IFDMA (from) as every output symbol is a repeated version of the input symbol in time domain while LFDMA output symbols has exact version of input symbols at N-multiple sample positions. So, the IFDMA has same PAPR as conventional single carrier signal.

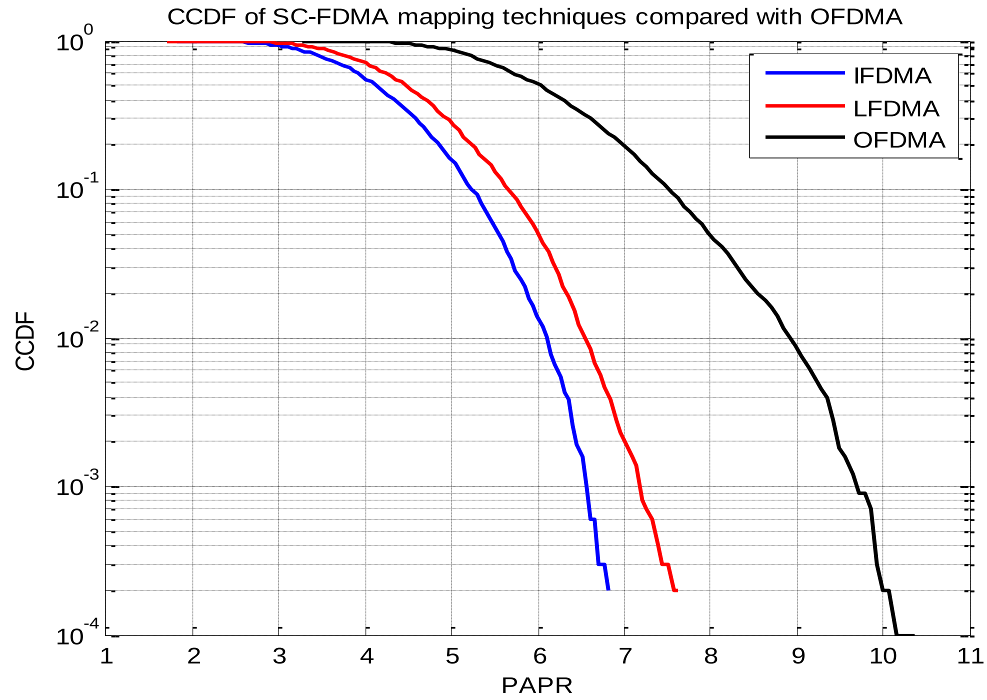


Figure3.11: Comparison of PAPR of IFDMA and LFDMA with OFDMA

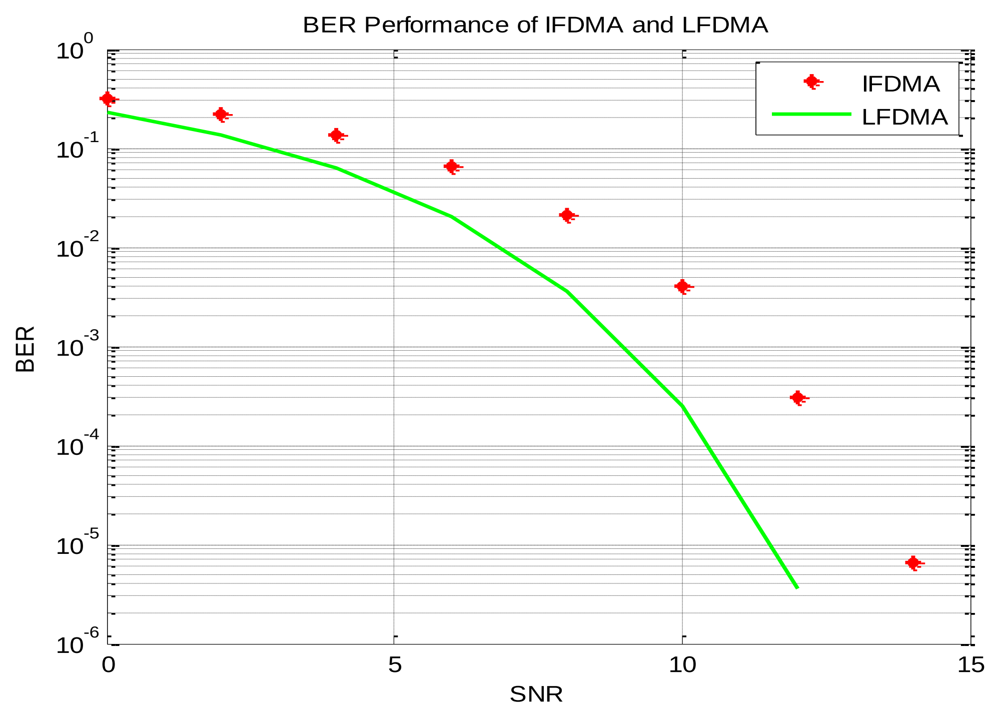


Figure 3.12: Bit Error Rate performance of IFDMA and LFDMA

PARAMETER	VALUE					
Channel Bandwidth (MHz)	1.4	3	5	10	15	20
Number of Resource Block	6	15	25	50	75	100
Number of occupied subcarriers	72	180	300	600	900	1200
IFFT/FFT Size	128	256	512	1024	1536	2048
Sub-carrier Spacing Δf (KHz)	15 (7.5)					
Sampling frequency (MHz)	1.92	3.84	7.68	15.36	23.04	30.72
Samples/slot	960	1920	3840	7680	11520	15360
CP size T_{CP} — Normal CP ($\Delta f = 15\ kHz$)	5.21 µs (first symbol of the slot) 4.69 µs (other symbols of the slot) $N_s = 7$ symbols/slot $N_{CP}(l) = \begin{cases} 160 & l = 0 \\ 144 & l = 1,2,\dots 6 \end{cases}$					
CP size T_{CP} — Extended CP ($\Delta f = 15\ kHz$)	16.67 µs $N_s = 6$ symbols/slot $N_{CP}(l) = 512 \quad l = 0,1,\dots .5$					
CP size T_{CP} — Extended CP ($\Delta f = 15\ kHz$)	33.33 µs $N_s = 7$ symbols/slot $N_{CP}(l) = 512 \quad l = 0,1,2$					

Table 3.1: LTE Interface OFDMA/SC-FDMA Parameters

3.4 CHANNEL MODELS

An underlying approximate model of the Radio Propagation Channel [21] forms the basis for calculation of the effects of channel on the transmitted data. The receiver is able to recover the transmitted data accurately as long as it can keep track of the time-varying channel models. The channel models are described below in section 4.3 of this chapter.

3.4.1 Wireless Channel Characteristics:

The Mobile Fading Channels are a crucial part of the wireless communication system because for proper transmission of data, an efficient channel model is required for analysis, design and deployment of the communication system. The performance and complexity of signal processing algorithms and designing transmitter and receivers all greatly depend on the methods employed to model mobile fading channels. True knowledge of the mobile fading channels is the central requirement for designing a wireless communication system.

Designing of wireless system suffers from the multifaceted propagation processes. The transmitted data signal go through different propagation mechanism before arriving at the receiver which means the signal travels over multiple paths. This is known as Multipath Propagation where different paths have different attenuations. The basic Multipath Propagation mechanisms include

- Free space or Line of Sight propagation
- Reflection, caused due to the interaction of electromagnetic waves with large objects having dimensions much greater than the wavelength of interacting electromagnetic waves.
- Diffusion or Scattering, caused due to objects having irregular size or shape and a wavelength comparable to the interacting electromagnetic waves.
- Diffraction, due to bending of electromagnetic waves around corners of buildings.
- Refraction, because of the objects that absorb energy partially.

The signal propagation over multipath models results in attenuation of the signal because of Mean Path Loss along with Macroscopic or large-scale fading and Microscopic or small-scale fading.

Large buildings or objects having large sizes causes obstruction in the path of the signal, also referred to as macroscopic fading. This is modelled by the local mean of a fast fading signal. This is a function of distance d between the transmitter and receiver proportional to the nth power of d relative to the reference distance d_0.

$$\overline{L_p}(d) = L_s(d_0) + 10n\log\left({}^{d}/_{d_0}\right) \quad \ldots\ldots\ldots\ldots (3.8)$$

The path loss is a random variable with log normal distribution about mean path loss $\overline{L_p}(d)$ and is given as

$$L_p(d) = L_s(d_0) + 10n\log\left({}^{d}/_{d_0}\right) + X \quad \ldots\ldots\ldots\ldots. (3.9)$$

Where $X \sim N(0, \sigma^2)$ denote a zero mean Gaussian Random Variable with Standard deviation n. The value of n depends on frequency, antenna heights and propagation environment.

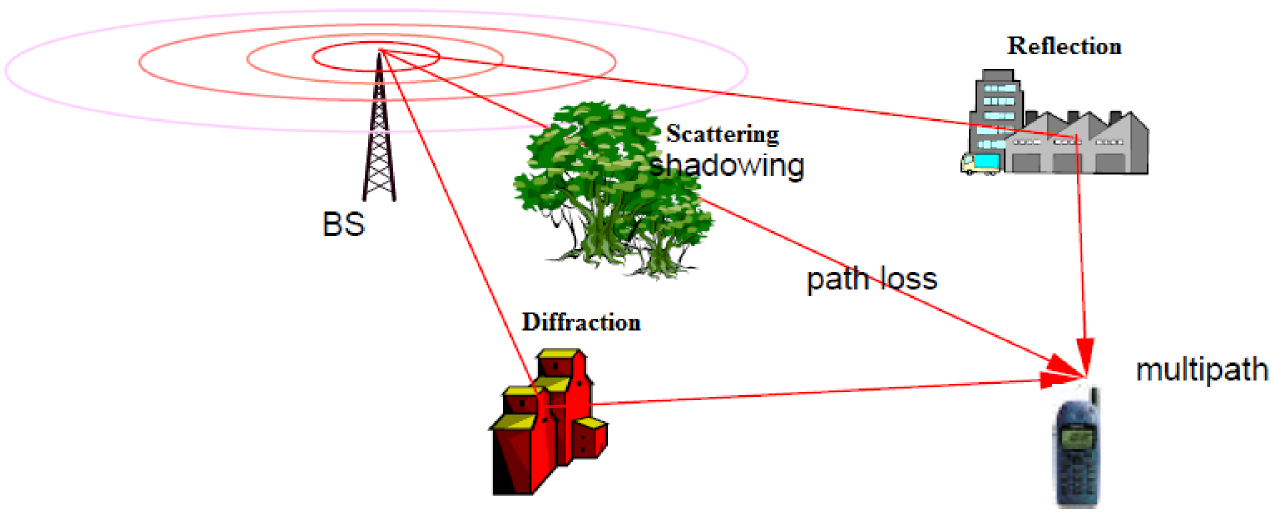


Figure 3.13: An example of Multipath Propagation Model

Microscopic fading occurs because of scattering or small scale objects and is defined as the rapid variations of the signal in time and frequency. When the received signal is a summation of the line of sight (LOS) component along with the scattered components results in an envelop $r(t)$ has a Rician Probability Distribution Function (PDF) and is known as Rician Fading. In the absence of LOS, Rician PDF approaches to Rayleigh PDF

$$f(r) = \frac{r(K+1)}{\sigma^2}\, exp\left[-K - \frac{(K+1)r^2}{2\sigma^2}\right] I_0\left(\frac{2r}{\sigma}\sqrt{K(K+1)/2}\right)\ldots\ldots\ldots\ldots. (3.10)$$

Where K is the Rician Factor and I_0 is a zero-order modified Bessel Function of First Kind.

When the transmitter/receiver is mobile (or moving) or the fading occurring from scattering result in Time varying Fading. The frequency variation of the channel is characterized as Doppler Spread and in time domain it is referred to as Coherence Time. There are two types of degradation effects caused by the relationship between the excess time delay $\tau_m$and symbol time τ_s: Frequency Selective Fading and Flat Fading.

Whenever the multipath components of a symbol reaches beyond the symbol duration i.e. $\tau_m > \tau_s$ Causing the Frequency Selective Fading. But ISI occurs as a consequence of this condition which can be mitigated as several multipath components are separable. When the symbol's multipath components reach with a delay within the symbol duration i.e. $\tau_m < \tau_s$ Results in a condition known as Flat Fading where the multipath components are Unresolvable. Here, ISI doesn't follow as there is no overlap between adjacent received symbols.

3.4.2 Propagation Aspects and Parameters:

As we know, characterization of the behavior of a Multipath channel is required to model a channel. In order to do this, the concepts of Doppler spread, Coherence time, Delay spread and coherence Bandwidth are used.

Delay spread

One of the most convenient ways to assess the performance of a wireless channel is to calculate the time dispersion or multipath delay spread. In its simplest form the delay spread, can be calculated as the overall extent of the path delays. But this can't be considered as a competent indicator of the system performance because the channels with same excess delay may have different power profile. So, an efficient way to calculate it is Root Mean Square (RMS) delay spread and it is calculated about the mean value of channel power delay profile making it statistical.

Mathematically, it is given as

$$\tau_{rms} = \sqrt{\frac{\sum_{n=0}^{N-1} p_n {(\tau_n - \tau_m)}^2}{\sum_{n=0}^{N-1} p_n}} \qquad \ldots\ldots\ldots\ldots\ldots (3.11)$$

Where

$$\tau_m = \frac{\sum_{n=0}^{N-1} p_n \tau_n}{\sum_{n=0}^{N-1} p_n}$$ is the mean delay excess

Coherence Bandwidth

In the frequency domain, the band of frequencies over which the amplitudes of frequency components are correlated is known as Coherence bandwidth. The behavior of the channel over coherence bandwidth does not change, and it is inversely proportional to the delay spread. This concept also can be used to distinguish between the flat fading channel and frequency selective channel as follows:

- When the coherence bandwidth is much greater than the signal bandwidth i.e. $B_c \gg B_s$, it is a Frequency Flat fading where equal fading is experienced by all the components.
- When the coherence bandwidth is less than the signal bandwidth i.e. $B_c \ll B_s$, it is Frequency Selective Fading [22]where each component experiences different quantity of fading. Since, coherence bandwidth is less than signal bandwidth it behaves as a filter.

Doppler Spread

Whenever the receiver is moving the concept of Doppler spread comes into consideration. Due to the motion of the receiver, all attributes of the transmitted signal (like amplitude and phase) vary as a function of time according to the speed [23]. For an unmodulated carrier, the output is varying with time and has a non-zero spectral width that is Doppler spread. When only one path exists between the transmitter and receiver, there is no Doppler spread along with a simple shifting of the carrier frequency (Doppler Frequency shift) at the transmitter.

Coherence Time

It is defined as the duration over which the characteristics of a channel are invariant. It is inversely proportional to the Doppler shift of the channel. Mathematically it is given as

$$T_c = \frac{1}{2\pi . \vartheta_{rms}} \quad \text{............ (3.12)}$$

Where ϑ_{rms} is the root mean square value of Doppler spread. It is critical for chores like designing channel estimation techniques, power control and error correction.

3.4.3 Multipath Channel Models:

In wireless communication, the channel models are developed to aid the designers in designing the system and verifying the system performance. During the design of LTE different performance requirements were taken into consideration like User Equipment(UE) and Base Station (BS) requirements , Radio Resource Management (RRM) requirements ensuring the competent use of available resources to provide high quality of service and RF performance requirements making it possible for LTE to exist with other systems. ITU has proposed a set of test environments in [24] which includes almost all the possible operating environments and user mobility. Here we will discuss about standard ITU Pedestrian and Vehicular environments.

ITU Pedestrian Channel Model

There are two kinds of pedestrian models specified by ITU, Pedestrian-A (Ped-A) and Pedestrian-B (Ped-B). For both the models pedestrians are located inside buildings or an open ground and the base stations are situated outside with lower antenna heights. It can follow either Rician or Rayleigh fading depending upon the user location. The mobile speeds taken under this model are less than or equal to 3 Km/h. Ped-A consists of 3 while Ped-B has 6 taps. The average power and relative delay of the channel models specified by ITU [24] is given below in table 3.2

Tap No.	Pedestrian-A		Pedestrian-B	
	Relative Delay (ns)	Average power (dB)	Relative Delay (ns)	Average Power (dB)
1.	0	0	0	0
2.	110	-9.7	200	-0.9
3.	190	-19.2	800	-4.9
4.	410	-22.8	1200	-8
5.	NA	NA	2300	-7.8
6.	NA	NA	3700	-23.9

Table 3.2: The average Power and Relative Delays of ITU Pedestrian Model

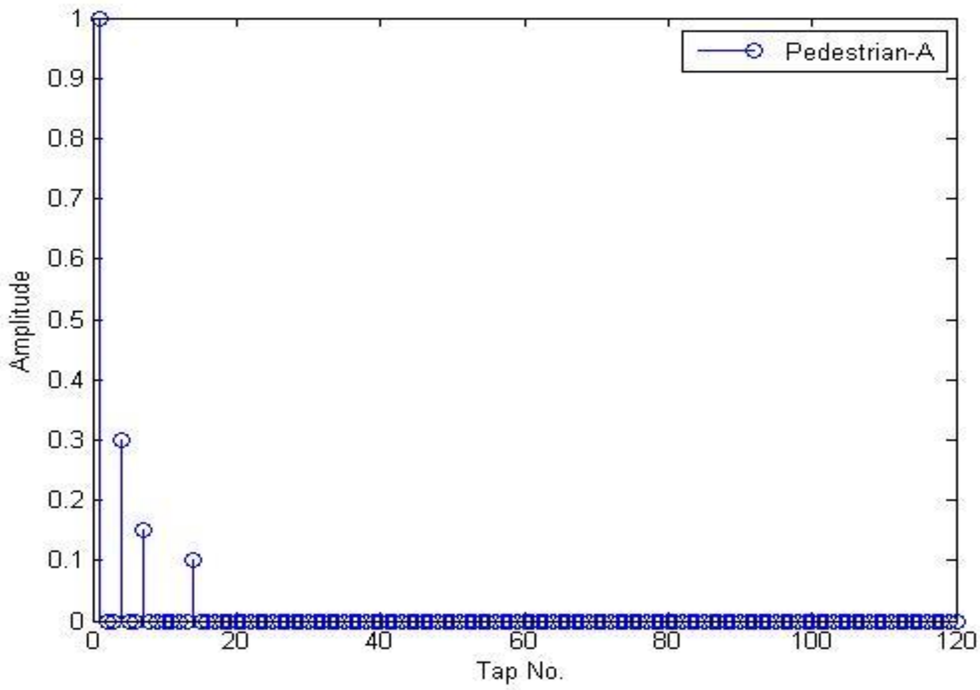


Figure 3.14: ITU Ped-A channel model Impulse Response

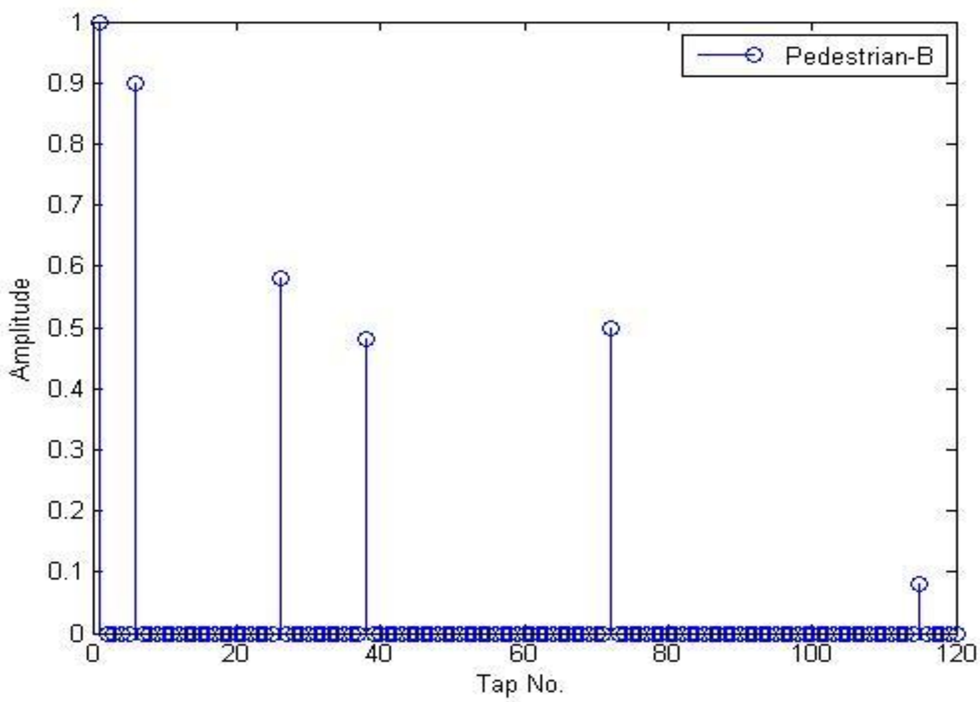


Figure 3.15: ITU Ped-B channel model Impulse Response

ITU Vehicular Channel Model

The vehicular model is distinguished from the pedestrian model in terms of larger size and high capacity of the cells, high transmission, and limited spectrum. As the signal power decreases with the increase in distance, for which the path loss exponent varies from 3 to 5 in the case of urban and suburban areas, while it has a much lower value in the rural area. Here we will be discussing Vehicular-A (Veh-A) channel model whose average power and relative delays are specified in Table 4.2. The mobile speeds taken into consideration are 30 Km/h, 120 Km/h and 350 Km/h.

Tap No.						
Average Power (dB)	**0**	**-1.0**	**-9.0**	**-10.0**	**-15.0**	**-20.0**
Relative Delay (ns)	**0**	**310**	**710**	**1090**	**1730**	**2510**

Table 3.3: The average Power and Relative Delays of ITU Vehicular Model

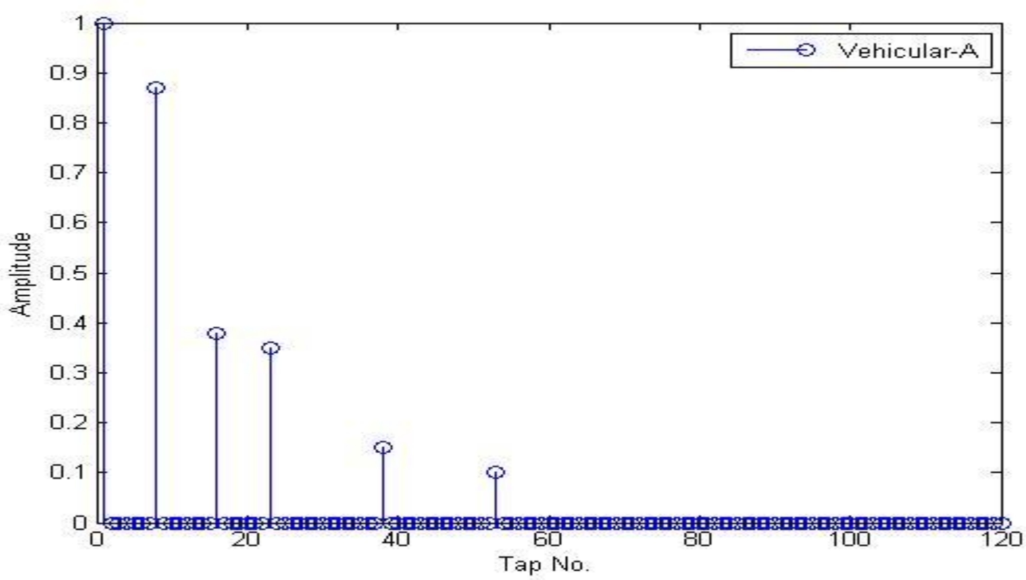


Figure3.16: ITU Veh-A channel model Impulse Response

3.4.4 Extended ITU Models:

The evolution of the future generation networks required a large number of changes to be made to the technology while the increase in quality of service required higher transmission bandwidth. So, larger bandwidth is required by the LTE channel models [25] to justify the fact that channel impulses are related to delay resolution of the receiver. The LTE channel models are based on ITU models and are nothing but Extended ITU channel models which are named as Extended Pedestrian-A (EPA), Extended Vehicular-A (EVA) and Extended TU (ETU). They are classified on the basis of low, medium and high delay spreads. The channel models used to model outdoor environments of the urban and suburban areas are EVA and ETU while the EPA is used to model indoor environments. The average power and relative delays of the EPA, EVA and ETU Channel models is shown in Table 4.3, 4.4 and 4.5 respectively.

Tap No.							
Average Power (dB)	**0**	**-1.0**	**-2.0**	**-3.0**	**-8.0**	**-17.2**	**-20.8**
Relative Delay (ns)	**0**	**30**	**70**	**80**	**110**	**190**	**410**

Table 3.4: The average power and delays of EPA channel model

Tap No.									
Average Power (dB)	**0**	**-1.5**	**-1.4**	**-3.6**	**-0.6**	**-9.1**	**-7.0**	**-12**	**-16.9**
Relative Delay (ns)	**0**	**30**	**150**	**310**	**370**	**710**	**1090**	**1730**	**2510**

Table 3.5: Average Power and Delays of EVA channel model

Tap No.									
Average Power (dB)	**-1.0**	**-1.0**	**-1.0**	**0.0**	**0.0**	**0.0**	**-3.0**	**-5.0**	**-7.0**
Relative Delay (ns)	**0**	**50**	**120**	**200**	**230**	**500**	**1600**	**2300**	**5000**

Table 3.6: Average Power and Delays of ETU channel model

The above LTE channel models have low, medium and high Doppler frequencies of 5 Hz, 70 Hz and 900 Hz. The delay spread and the Doppler frequencies can be combined as specified in [26] in the following way; EPA 5 Hz, EVA 5Hz, EVA 70 Hz and ETU 70 Hz.

CHAPTER-4

CHANNEL ESTIMATION TECHNIQUES

In this chapter, we will discuss the techniques used for channel estimation in LTE[28]. Channel estimation is considered as a very crucial part of designing a receiver in mobile communication. Without channel estimation, the data transmitted through a time-varying channel cannot be decoded properly at the receiver. As we know, to recover the transmitted data accurately the effects of the channel on the data must be estimated correctly. For this LTE employs coherent detection where the response of the channel is already known at the receiver.

There are various ways in which Channel estimation can be performed like Parametric Model, Blind or Pilot Based, adaptive or Non-adaptive. The parametric method runs on the assumption of a particular channel model and calculates the parameters of that model while the Non-Parametric method does not rely on a certain channel model and estimates the frequency response. The most commonly applied method is the Pilot based Channel Estimation and is employed in a system where the data transmitted by the sender is known. On the other hand, practically Blind estimation is not commonly used because it relies on some of the properties of the signal. And the time-varying channels employ Adaptive Channel Estimation.

In this chapter we will discuss Pilot-Based Channel Estimation Method and evaluate its performance in both uplink and downlink LTE. Two types of channel estimation techniques Least squares (LS) and Minimum Mean Squared Error (MMSE) are described in section 5.2. The performance of these estimators in the Uplink and Downlink LTE is analyzed in section 5.3.

4.1 Pilot-Based Channel Estimation:

In OFDM Channel estimation is taken to be a 2-D process i.e. the channel impulse response is a function of both time and frequency. So, estimation is to be performed in frequency as well as time domain. Due to practical difficulty of implementing estimation in 2-D, one dimensional estimation methods are used. They are applied in such a way that it gives an idea of 2-D estimator, at first the channel is estimated in one dimension (like, time) followed by estimation in another domain (frequency).

The approach to the Pilot-Based channel estimation consists of three steps, firstly the pilots are extracted from the known positions. Secondly, the channel estimation is performed on those reference signals followed by the last step which is Interpolation where the channel is estimated at the rest of the positions. Interpolation uses the estimates of the two nearest pilots to estimate the channel at the places between those pilots.

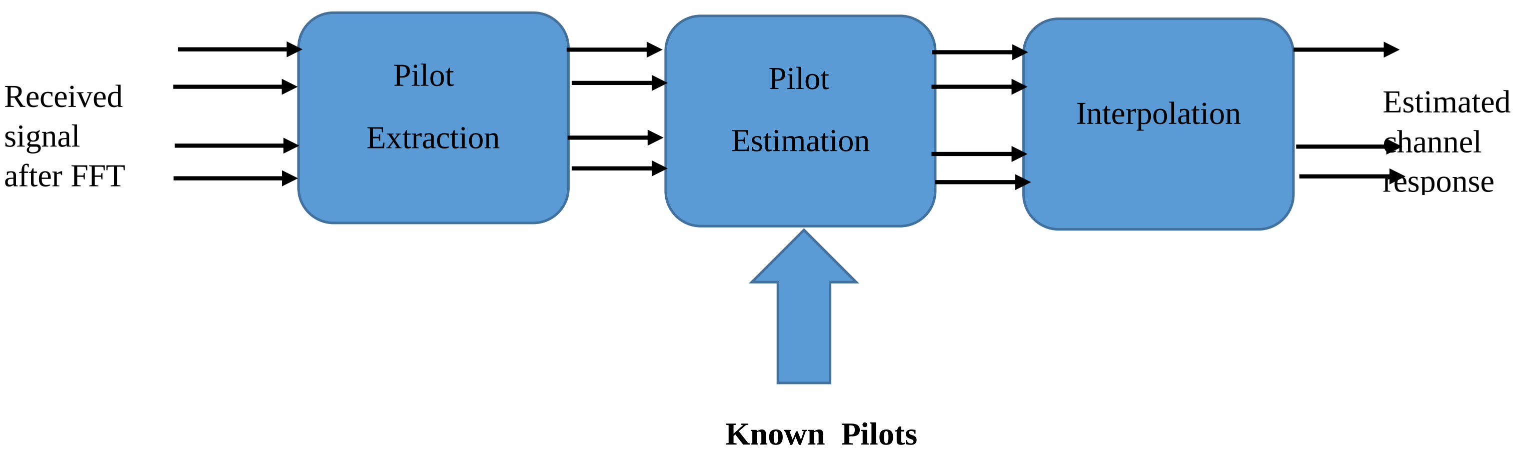


Figure 4.1: Approach to Pilot Based channel estimation

4.2 Channel Estimation Techniques:

Assuming the orthogonality of all the subcarriers i.e. no ICI, the following diagonal matrix represents the pilot symbols for N subcarriers

$$A = \left[\begin{bmatrix} A(0) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & A(N-1) \end{bmatrix}\right]$$

Where, A[k] is the representation of training symbol tone at the k^{th} subcarrier with zero mean and variance σ^2 for k = 0, 1, 2….. N-1.And assuming that h[k] is the gain of the channel at each k^{th} subcarrier, the received signal can be given as

$$y \triangleq \begin{bmatrix} y(0) \\ y(1) \\ \vdots \\ y(N-1) \end{bmatrix} = \begin{bmatrix} A(0) & 0 & \cdots & 0 \\ 0 & A(1) & \cdots & 0 \\ \vdots & \ddots & & 0 \\ 0 & \cdots & & A(N-1) \end{bmatrix} \begin{bmatrix} h(0) \\ h(1) \\ \vdots \\ h(N-1) \end{bmatrix} + \begin{bmatrix} n(0) \\ n(1) \\ \vdots \\ n(N-1) \end{bmatrix}$$

$$y = Ah + n \quad \ldots\ldots (4.1)$$

4.2.1 Least Square Estimation

Using the knowledge we have of the pilots at subcarrier of the transmitted data A_{pk} and received signal y_{pk}, the transfer function of the channel can be expressed as

$$\hat{h}_{pk} = \frac{y_{pk}}{A_{pk}} + \frac{n_{pk}}{A_{pk}} = h_{pk} + z_{pk} \ldots\ldots.. (4.2)$$

As we know, the estimation of channel in LTE is a two dimensional concept, therefore transfer function is modelled as linear weighted sum of 2-D basis functions evaluated at k^{th} subcarrier and m^{th} OFDM symbol and represented as h(m,k)

$$h(m,k) = \sum_{l=0}^{N-1} \propto_l \ \emptyset_l\,(m,k) \ldots\ldots \ (4.3)$$

where $\propto_l$ is the l^{th} basis function coefficient, N is the number of Basis function and $\emptyset_l(m,k)$ is the l^{th} basis function sampled at k^{th} subcarrier and m^{th} OFDM symbol.

By keeping one of the indices constant i.e. time or frequency the above equation becomes

$$h_k = \sum_{l=0}^{N-1} \propto_l \ \emptyset_l\,(k) \ \ldots\ldots\ldots\ldots \ (4.4)$$

So, at the pilot tone subcarriers the channel transfer function is given as

$$\hat{h}_{pk} = \sum_{l=0}^{N-1} \propto_l \ \emptyset_l\,(pk) + z_{pk} \ \ldots\ldots (4.5)$$

The above function can be expressed in matrix form as follows

$$\begin{bmatrix} \hat{h}_0 \\ \hat{h}_p \\ \hat{h}_{2p} \\ \vdots \\ \hat{h}_{N_p-1} \end{bmatrix} = \begin{bmatrix} \emptyset_0(0) & \emptyset_1(0) & \dots & \dots & \emptyset_{N-1}(0) \\ \emptyset_0(p) & \emptyset_1(p) & \dots & \dots & \emptyset_{N-1}(p) \\ \vdots & \vdots & & & \vdots \\ \vdots & \vdots & & & \vdots \\ \emptyset_0(N-1) & & & & \emptyset_{N-1}(p) \end{bmatrix} \begin{bmatrix} \propto_0 \\ \propto_1 \\ \propto_2 \\ \vdots \\ \propto_{N-1} \end{bmatrix} + \begin{bmatrix} z_0 \\ z_1 \\ z_2 \\ \vdots \\ z_{N-1} \end{bmatrix}$$

……….. (4.6)

The LS estimation method calculates the transfer function in such a way that the distance between the actual channel vector h and estimates channel vector $\hat{h}$ is minimum.

$$J(\hat{h}) = \|y - \emptyset\, h\|^2 = (y - \emptyset\, h)^H (y - \emptyset\, h)$$

$$= y^H y - y^H \emptyset\, h - \emptyset^H y h^H + \emptyset^H \emptyset h h^H$$

Now, taking the derivative and equating it to zero we have

$$\frac{\partial\; J(\hat{h})}{\partial h} = 0$$

We get the Least Square estimate as

$$h_{LS} = \emptyset^{-1} \hat{h} \qquad \text{…….. (4.7)}$$

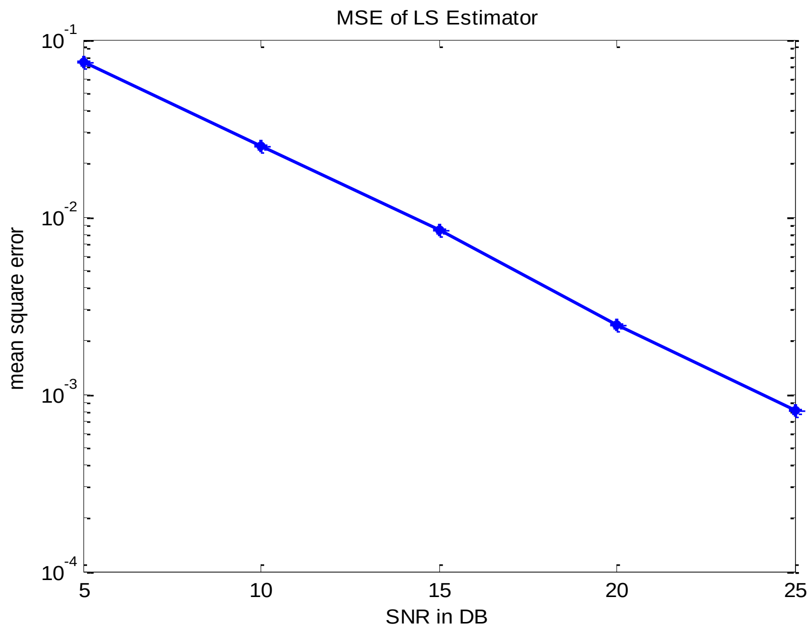


Figure 4.2: Mean Square Error of a least square Estimator

4.2.2 Minimum Mean squared Error (MMSE) Estimation

The Least Square estimation discussed above is attractive because of its simplicity in computation but it is susceptible to noise and does not have a good performance. Another approach to estimate the channel in LTE is using the MMSE estimator which exploits the second order statistics of the transfer function in such a way that the mean square error is minimized. The channel estimate through MMSE at the pilot tones can be calculated as given below:

$$h_{MMSE} = R_{p\hat{p}} \, R_{\hat{p}\hat{p}}{}^{-1} \, y_p$$

$$= R_{pp} \, \emptyset_p{}^H \left[\emptyset_p R_{pp} \emptyset_p{}^H + \sigma^2 \, (\emptyset \, \emptyset^H)^{-1}\right]^{-1} h_{LS}$$

$$= R_{pp} \left[R_{pp} + \sigma^2 \, I\right]^{-1} h_{LS}$$

$$= R_{pp} \left[R_{pp} + \frac{1}{SNR} \, I\right]^{-1} h_{LS} \qquad \ldots\ldots\ldots (4.8)$$

$$R_{p\hat{p}} = E\left\{h_{pk} \, y_p{}^H\right\}$$

$$= E\left\{h_{pk} \, (h_{pk} + z_{pk})^H\right\}$$

$$= R_{pp} \emptyset_p{}^H$$

$$R_{\hat{p}\hat{p}} = E\left\{y_p \, y_p{}^H\right\}$$

$$= E \left\{(h_{pk} + z_{pk}) \, (h_{pk} + z_{pk})^H\right\}$$

$$= \emptyset_p \, R_{pp} \, \emptyset_p{}^H + \sigma^2 \, I$$

Where $R_{\hat{p}\hat{p}}$ is the Auto correlation Matrix and $R_{p\hat{p}}$ is the Cross-Correlation Matrix.

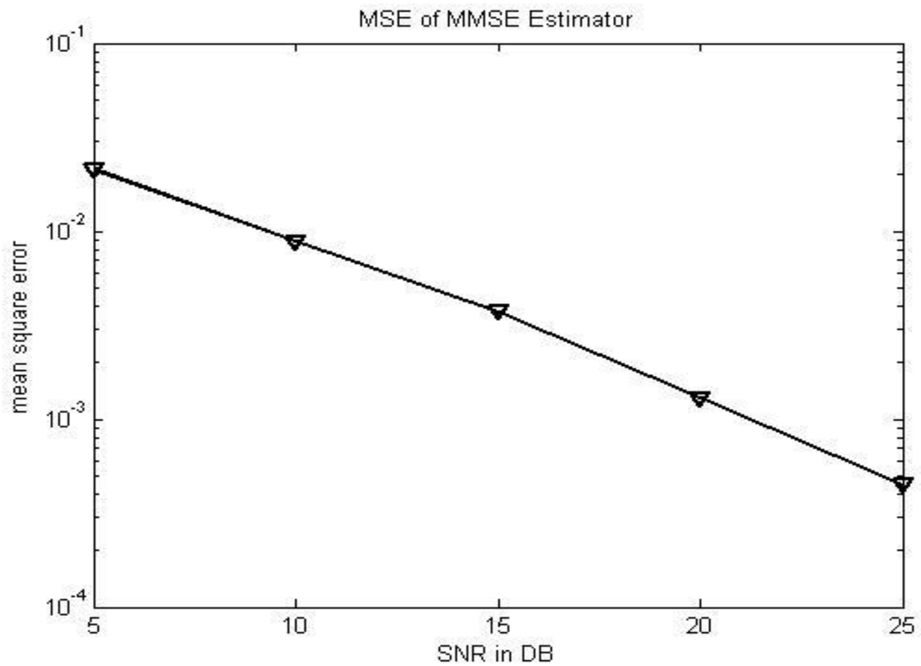


Figure 4.3: Mean Square Error of an MMSE Estimator

The MMSE estimator performs much better than the LS estimator especially under low SNR which is shown in figure 5.6 where MSE of both the estimators is compared.

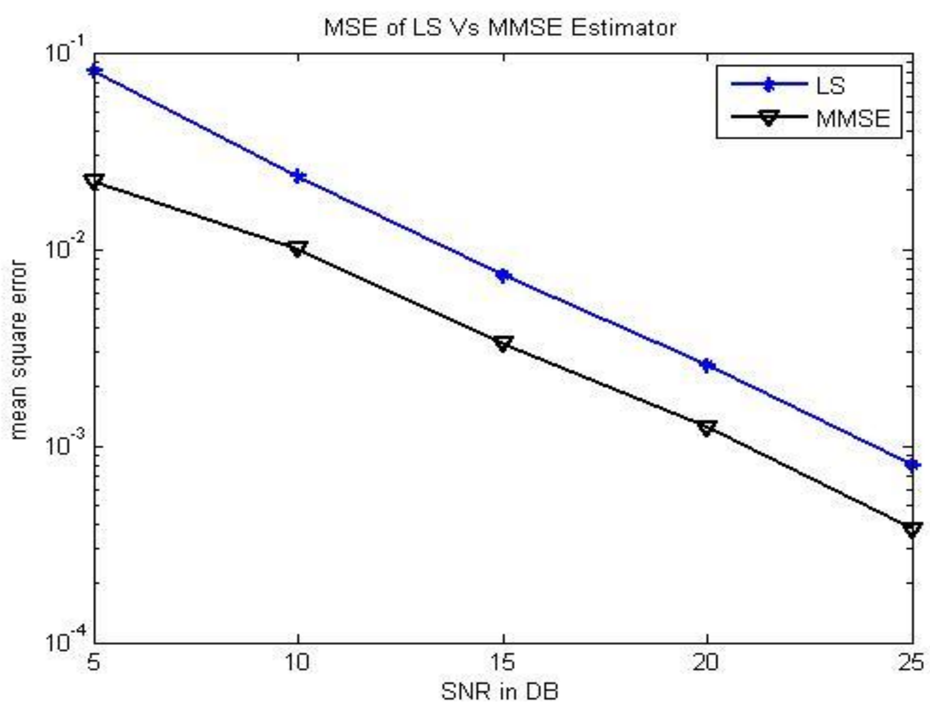


Figure 4.4: Comparison of the MSE of MMSE and LS estimators.

4.3 Performance Analysis in LTE Downlink system:

Parameters	Values
Bandwidth	10 MHz
Number of Iterations	600
FFT Size	1024
CP length	4 μs
Subcarrier spacing	9.765 KHz
Input block size	16
Input FFT size	16
Sample rate	3.84 MHz
Number of transmit antennas	1
Number of receive antennas	1
Modulation	QPSK

Table 4.1: Parameters assumed in the Simulation

In this section we are going to analyze the performance of the estimators in a Single-Input Single-Output LTE downlink system using MATLAB as a simulation platform. The parameters used in the simulation are specified in Table 8.1 below. The Multipath channel models used are ITU Pedestrian-A and Vehicular-A already discussed in chapter 4. The Delay and Power profile of both the channels is given in chapter 4. The Pedestrian channel model has a shorter delay as compared the Vehicular model resulting in a severe frequency selectivity in vehicular model.

Figure 5.5 shows the BER performance of the Least Square Estimator in LTE Downlink where OFDMA is used as the transmission scheme. The LS estimator provides adequate estimate of the channel in pedestrian model but its performance deteriorates severely in vehicular environment.

Figure 5.6 shows the BER Performance of the Minimum Mean Square Error Estimator (MMSE) in the pedestrian and vehicular environment and compared with performance in AWGN channel. Its is shown that the performance of MMSE estimator degrades in the Vehicular environment like LS estimator but it is able to give a better estimate than the LS estimator.

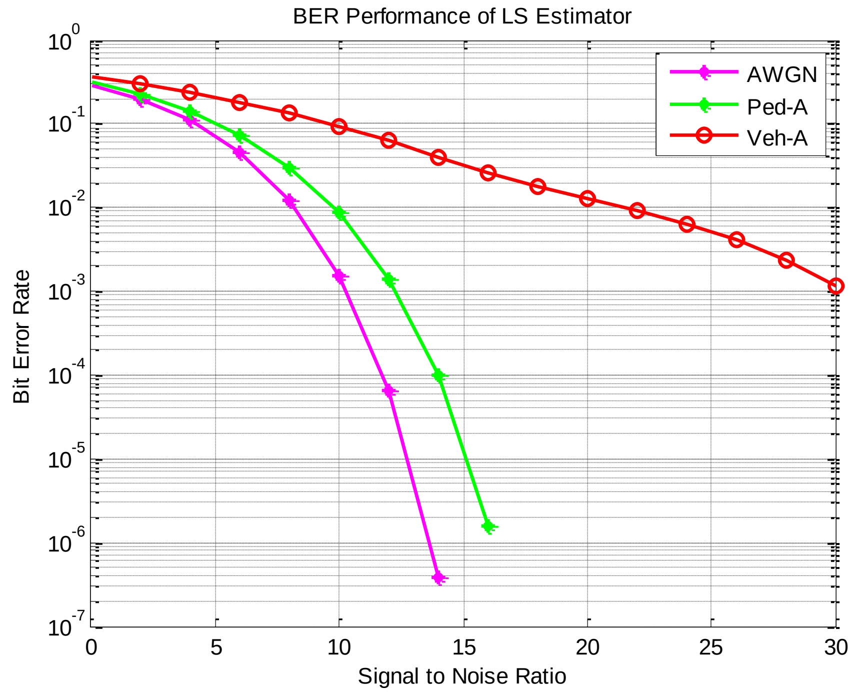


Figure 4.5: Bit Error Rate Performance of LS Estimator in LTE Downlink for Different Multipath Channel Models

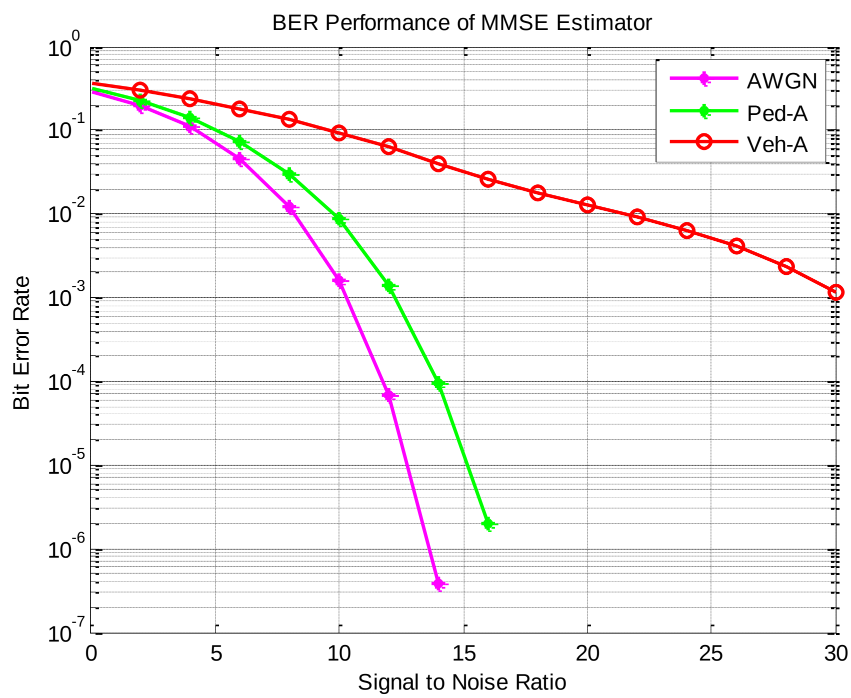


Figure 4.6: Bit Error Rate Performance of MMSE Estimator in LTE Downlink for Different Multipath Channel Models

4.4 Performance Analysis in LTE Uplink system:

Here, we will discuss the Uplink transmission technique SC-FDMA and the performance of the estimators will be evaluated with the same parameters and multipath channel models as discussed above. The two types of subcarrier mapping schemes used in SC-FDMA i.e. Localized FDMA and Interleaved FDMA will be evaluated here to find out which performs better. The performance is evaluated in terms of Bit Error Rate (BER).

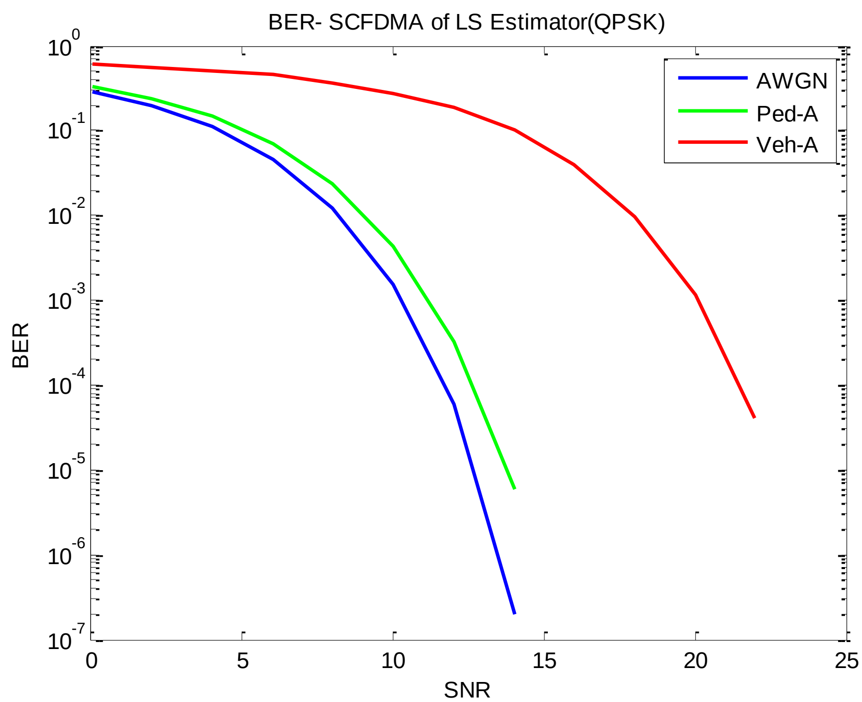


Figure4.7: BER Performance of an LS estimator in ITU Pedestrian and Vehicular along with AWGN Channel

From Figure 5.7 shows the Bit Error Rate performance of the LS Estimator in different multipath channels specified by ITU. It is seen from the figure that the LS estimator performs best in AWGN and in Pedestrian environment its performance is very similar to AWGN. But in the Vehicular environment where the channel is time-varying, its performance is degraded.

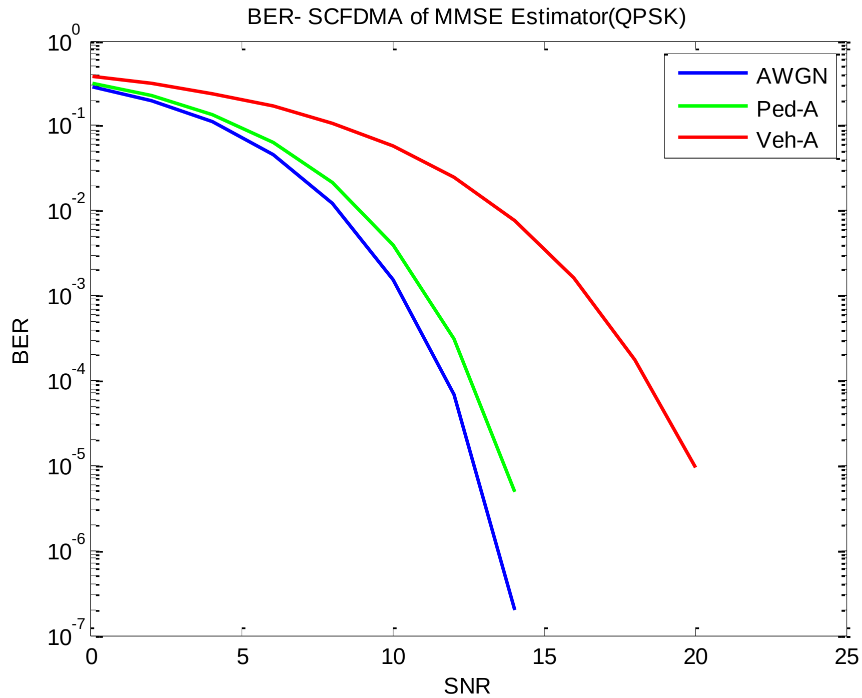


Figure 4.8: BER Performance of an MMSE estimator in ITU Pedestrian and Vehicular along with AWGN Channel

From Figure 5.8 shows the Bit Error Rate performance of the MMSE Estimator in different multipath channels specified by ITU and compared with AWGN channel using QPSK modulation technique. From the above figure it is evident that the MMSE estimator definitely performs better than the LS estimator. In the time-varying environment MMSE estimator is more efficient than the LS estimator making it reliable to use in a vehicular environment. But its performance too degrades in a high mobile speed environment.

Now, the performance of the LS and MMSE estimators will be evaluated in the different subcarrier schemes of SC-FDMA and we will observe the effects of the mapping schemes on the performance of the LS estimator. At first the performance of estimators will be observed in the Pedestrian and then in the Vehicular environment.

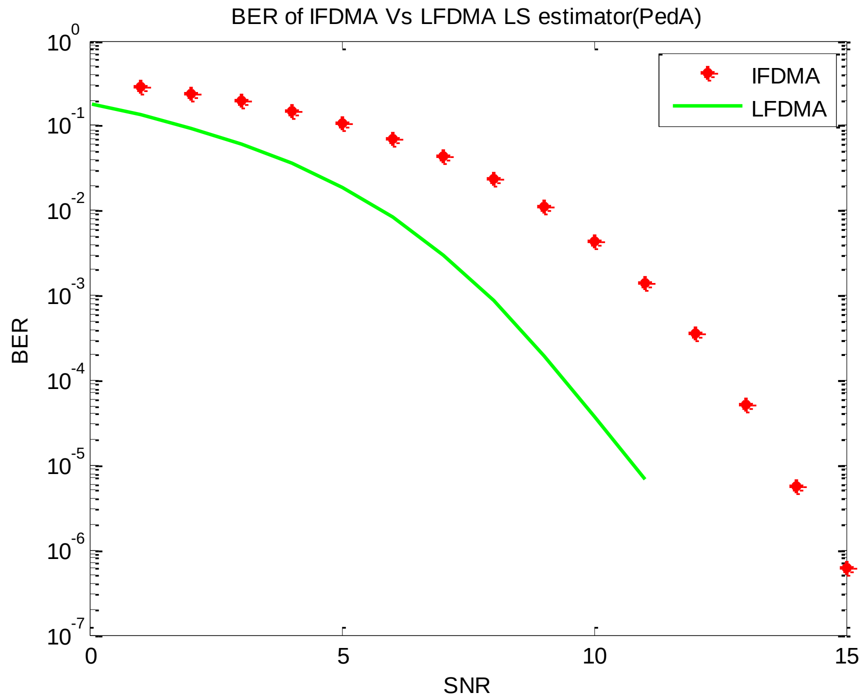


Figure 4.9: Comparison of BER performance of Subcarrier mapping schemes using LS Estimation Technique in Pedestrian-A Channel Model

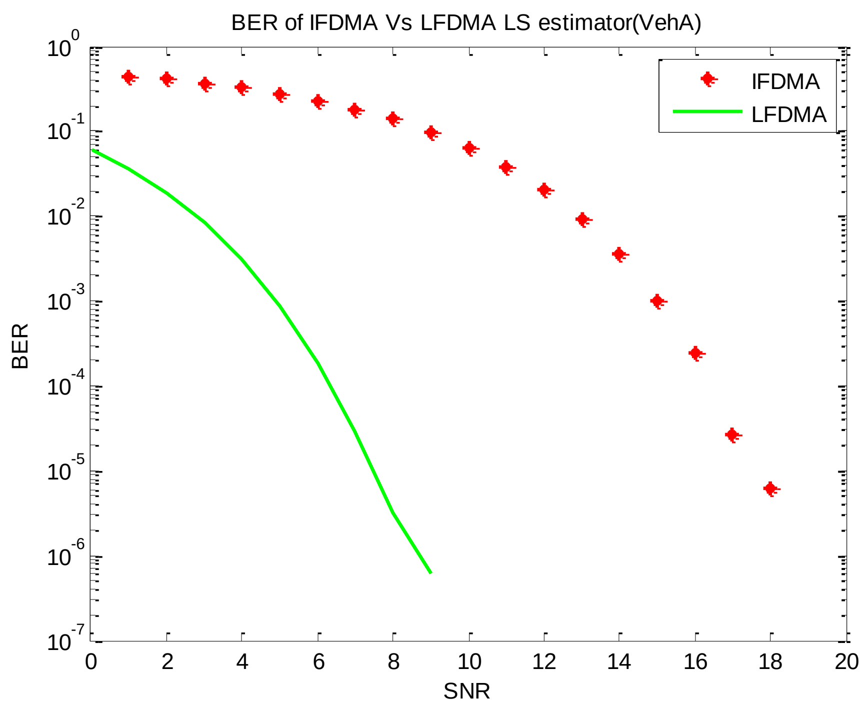


Figure 4.10: Comparison of BER performance of Subcarrier mapping schemes using LS Estimation Technique in Vehicular-A Channel Model

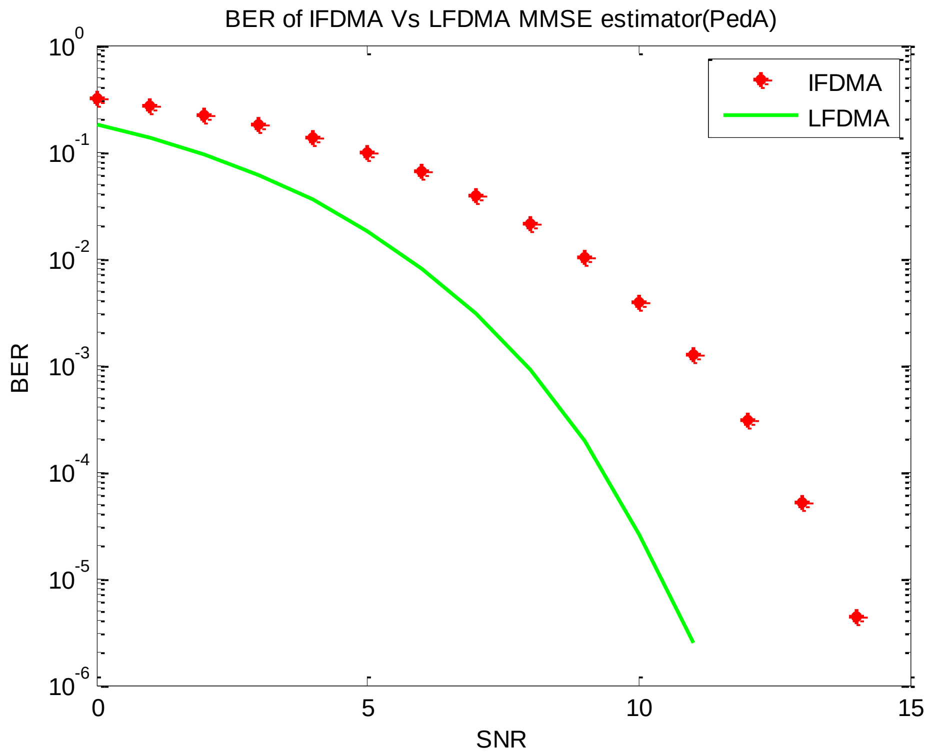


Figure 4.11: Comparison of BER performance of Subcarrier mapping schemes using MMSE Estimation Technique in Pedestrian-A Channel Model

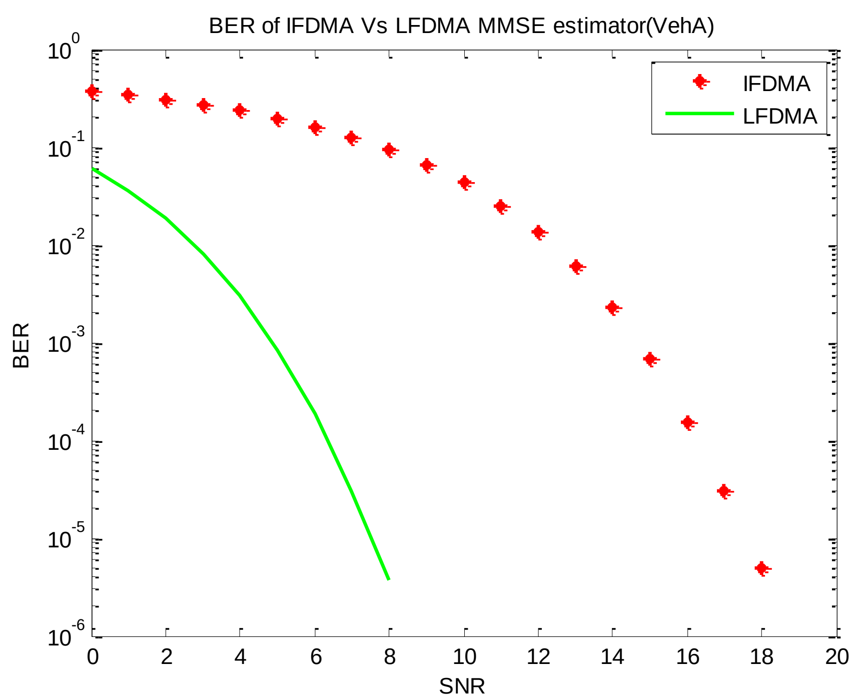


Figure 4.12: Comparison of BER performance of Subcarrier mapping schemes using MMSE Estimation Technique in Vehicular-A Channel Model

Figure 5.9, 5.10, 5.11.and 5.12 shows the performance of the LS and MMSE estimation Techniques in multipath models of SC-FDMA for different subcarrier mapping schemes. It is evident from the above figures that the LFDMA mapping performs better than the IFDMA in the pedestrian as well as vehicular environment. The subcarrier mapping schemes also enhances the performances of the estimators. We can see that the performance of the LS estimator has improved tremendously by using LFDMA mapping.

CHAPTER-5

CONCLUSION

This thesis analyzes some of the aspects of Channel Estimation of Long Term Evolution in uplink as well as downlink. The thesis mainly focuses on analyzing the performance of Least Square and Minimum Mean Square Error Estimators in the uplink and downlink in various multipath models. Performance. Along with this we also analyzed the subcarrier mapping schemes used in SC-FDMA like Localized FDMA and Interleaved FDMA. The performances are evaluated in terms of Bit Error Rate. In the downlink both the estimators perform well in the pedestrian environment giving a performance almost similar to AWGN channel. So, either of the estimators can be used in Pedestrian environment. But in the Vehicular environment with high mobile speed the performance of LS estimator degrades exponentially but the MMSE estimator performs better than the LS estimator despite the degradation of its performance.

In the Uplink at first we observed the LS and MMSE Estimation Techniques without the subcarrier mapping. The results show that the performance of the estimators deteriorates with the increase in mobile speed but its better as compared to OFDM. The MMSE estimator outperforms the LS estimator again. Further, subcarrier mapping schemes are applied and the effects were observed. It was seen that the performance of both the estimators greatly improves in Pedestrian and Vehicular channel models for both the subcarrier schemes. Among them the LFDMA mapping scheme has a lesser BER than IFDMA. The MMSE estimator performs better using these mapping schemes also, making it a suitable estimator in both the environments. Now, we can see that IFDMA has a much lesser PAPR than LFDMA or we can say that IFDMA is an efficient way of reducing PAPR but at the cost of high BER. In other words, there could be a trade-off between the schemes used according to the requirement of the system. And because of its lesser error LFDMA is considered to perform better.

FUTURE SCOPE

Here, only LS and MMSE estimators were used, in the future work can be done towards improving the performance of the estimators by using the time-varying channel estimation algorithms and other such techniques. Also certain work can be done to reduce the bit error rate of IFDMA retaining its low PAPR performance.

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