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LTE UPLINK MODELING AND CHANNEL ESTIMATION

Master Thesis Performed in Computer Engineering Division
by

Mohsin Niaz Ahmed

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Abstract

This master thesis investigates the uplink transmition from User Equipment (UE) to base station in LET (Long Term Evolution) and channel estimation using pilot symbols with parameter defined in 3GPP (3rd Generation Partnership Project) specifications. The purpose of the thesis was to implement a simulator which can generate uplink signal as it is generated by UE. The Third Generation (3G) mobile system was given the name LTE. This thesis focus on the uplink of LTE where single carrier frequency division multiple access (SC-FDMA) is utilized as a multiple access technique. The advantage over the orthogonal frequency division multiple access (OFDMA), which is used in downlink is to get better peak power characteristics. Because in uplink communication better peak power characteristic is necessary for better power efficiency in mobile terminals. To access the performance of uplink transmition realistic channel model for wireless communication system is essential. Channel models used are proposed by International Telecommunication Union (ITU) and the correct knowledge of these models is important for testing, optimization and performance improvements of signal processing algorithms. The channel estimation techniques used are Least Square (LS) and Least Minimum Mean Square Error (LMMSE) for different channel models. Performance of these algorithms has been measured in term of Bit Error Rate (BER) and Signal to Noise Ratio (SNR).

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This master thesis investigates the uplink transmition from User Equipment (UE) to base station in LET (Long Term Evolution) and channel estimation using pilot symbols with parameter defined in 3GPP (3rd Generation Partnership Project) specifications. The purpose of the thesis was to implement a simulator which can generate uplink signal as it is generated by UE. The third generation (3G) mobile system was given the name LTE. This thesis focus on the uplink of LTE where single carrier frequency division multiple access (SC-FDMA) is utilized as a multiple access technique. The advantage over the orthogonal frequency division multiple access (OFDMA), which is used in downlink is to get better peak power characteristics. Because in uplink communication better peak power characteristic is necessary for better power efficiency in mobile terminals. To access the performance of uplink transmition realistic channel model for wireless communication system is essential. I used channel models proposed by International Telecommunication Union (ITU) and the correct knowledge of these models is important for testing, optimization and performance improvements of signal processing algorithms. The channel estimation techniques used are Least Square (LS) and Least Minimum Mean Square Error (LMMSE) for different channel models. Performance of these algorithms has been measured in term of Bit Error Rate (BER) and Signal to Noise Ratio (SNR).

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All praises and thanks to Almighty God, the most beneficent and the most merciful, who gave me abilities and helped me to complete this thesis. I would like to express my gratitude to my supervisor Dr. Di Wu for his support and encouragement which has made the completion of this thesis. Through out my work he tried to help me with my misunderstanding, wrong concepts and his suggestions that helped to improve my technical and non technical skills as well.

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Contents

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Abbreviations

3G	Third Generations
3GPP	Third Generation partnership Project
BER	Bit Error Rate
BPSK	Binary Phase-Shift Keying
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
ICI	Inter Carrier Interference
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
ISI	Inter Symbol Interference
LB	Long Block
LS	Least Square
LTE	Long Term Evolution
Mbps	Mega bit per second
MHz	Mega Hertz
MMSE	Minimum Mean Square Error
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PAPR	Peak-to-Average Power Ratio
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
SNR	Signal to Noise Ratio
PedA	Pedestrian A
VehA	Vehicular A
WCDMA	Wideband Code Division Multiple Access

Symbols

$N_{\mathrm{RB}}^{\mathrm{UL}}$	Number of resource blocks for Uplink
$N_{\mathrm{RB}}^{\mathrm{UL}}$	Uplink bandwidth configuration, expressed in number of resource blocks
$N_{\mathrm{sc}}^{\mathrm{RB}}$	Resource block size , expressed as a number of subcarriers
$N_{\mathrm{symb}}^{\mathrm{PUSCH}}$	Number of SC-FDMA symbols carrying PUSCH in a subframe
$N_{\mathrm{symb}}^{\mathrm{UL}}$	Number of SC-FDMA symbols in an uplink slot
$N_{\mathrm{ID}}^{\mathrm{cell}}$	Physical layer cell identity
n_{cs}	Number of cyclic shifts
n_{RNTI}	Radio network temporary identifier
n_{f}	System frame number
n_{s}	Slot number within a radio frame
Δf	Subcarrier spacing
$N_{\mathrm{ZC}}^{\mathrm{RS}}$	The length of the Zadoff-Chu sequence

INTRODUCTION 1

From the first experiment by Guglielmo Marconi with radio communication, the communication industry witnessed tremendous growth in the past decades. The starting point of the communication industry was first generation (1G) analog cellular systems. The second generation (2G) digital system provided better voice quality and high data rate. The two widely deployed second generation (2G) cellular systems are GSM (global system for mobile communications) and CDMA (code division multiple access) [1]. Use of mobile communications increased rapidly and people want to communicate and share data with high data rate and good quality. But the Techniques used in 1G and 2G were not fulfilling the demands of users. These demands paved the way for evolution of Third Generation (3G) which supports a peak data rate of 2Mb/s in an indoor environment, Uplink to 144 kbps in a pedestrian environment, Uplink to 64 kbps in a vehicular environment [1]. Data capability in GSM was added later, in the first place it was designed for carrying only voice traffic.

The data traffic volume increased compare to voice traffic. To accommodate that High Speed Downlink Packet Access (HSDPA) and WCDMA was introduced in 3G which boosted data usage considerably [3]. Recently the increase of mobile data usage and emergence of new application like mobile TV, Web2.0 and other streaming contents motivated the 3rd Generation Partnership Project (3GPP) to work on the Long-Term Evolution (LTE) [4].

1.1 Background

3GPP was created in December 1998 and it is a co-operation between ETSI (Europe), ARIB/TTC (Japan),CCSA (China), ATIS (North America) and TTA (South Korea) by signing of the "The 3rd Generation Partnership Project" agreement in order to improve the UMTS (Universal Mobile Telecommunications System) mobile phone standard. The main objective of 3GPP was to produce technical specification and technical reports for a 3G Mobile System. The scope was subsequently amended to include the maintenance and development of the Global System for Mobile communication (GSM), technical specifications and technical reports including evolved radio access technologies (e.g. General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE))[8].

This was a first step toward centralizing the standards and technical documents to ensure global interoperability. These documents are structures as releases which contain several individual standards. Table1.1 shows the latest releases and emphasizes some of the specifications. Developments currently done by 3GPP (Release 7 and above) are under the title UMTS Long Term Evolution.

Functional freeze date	Version	Description
1999	Release 99	GSM specifications and the development of the new UTRAN radio access network.
2002	Release 5	Specification of High Speed Downlink Packet Access (HSDPA).
2004	Release 6	Specification of High Speed Uplink Packet Access (HSUPA).
2008	Release 7	Focuses on decreasing latency, improvements to QoS and real-time applications such as VoIP.
2008	Release 8	First **LTE** release.
2009	Release 9	SAES Enhancements, WiMAX and LTE/UMTS Interoperability.
2011	Release 10	**LTE Advanced** fulfilling IMT Advanced 4G requirements.
In progress	Release 11	Advanced IP Interconnection of Services.

Table 1.1 3GPP Releases [12]

1.2 Overview of LTE

- Performance and Capacity

The requirements and target for LTE is defined in 3GPP TR 25.913, the throughput should be 100 Mbps in downlink and 50 Mbps in Category 3 terminal which is ten times more then High speed Packet Access (HSPA) of Release 6. The multiple access schemes in LTE downlink uses Orthogonal Frequency Division Multiple Access (OFDMA) and uplink uses Single Carrier Frequency Division Multiple Access (SC-FDMA). For Uplink SC-FDMA is used to mitigate Peak to Average Power Ratio (PARP) issue which improves the efficiency of power amplifier. These multiple access solutions provide orthogonality between the users, reducing the interference and improving the network capacity [3].

- Simplicity

LTE support flexible carrier bandwidth from below 5MHz up to 20MHz. LTE also supports both FDD (Frequency Division Duplex) and TDD (Time Division Duplex). Operator can introduce LTE in new bands where it is easiest to deploy 10MHz or 20MHz carries and eventually deploy LTE in all bands.

1.3 Problem Statement

Thesis work focus on the implementation of Physical Uplink Shared Channel (PUSH) and Uplink Shared Channel (UL-SCH) for LTE uplink using MATLAB, which provided with a test simulation scenario that provides a means to test the performance of an LTE Uplink transmission and perform channel estimation. The basic goal of the thesis was to implement a simulator which can generate uplink signal as it is generated by UE.

1.4 Thesis Scope

The research on Uplink modeling and Channel Estimation for Long Term Evolution (LTE) is for Uplink with single input single output (SISO). The channel models used are proposed by ITU and the channel estimation techniques implemented are LS and LMMSE.

1.5 Thesis Layout

The Layout of the report is as follow:

In chapter 2 the theoretical background of frame structure and physical recourse block of LTE is described. Furthermore the basic principle of SC-FDMA, transmitter and receiver structure of uplink is also described. Chapter 3 explains the physical channels of uplink, from which focuses on Physical Uplink Shared Channel (PUSCH). Chapter 4 describes the steps involved in processing of transport channel. Chapter 5 investigates the generation of reference signal, channel models and channel estimation techniques. Simulation results and analysis are presented in Chapter 6, which shows the plots of channel estimation error and BER versus SNR plots using different modulation schemes and channel models. The conclusions can be found in Chapter 7, followed by the discussion of possible continuation of this thesis work.

LTE Physical Layer 2

2.1 Frame structure

Frame structure type 1 is applicable to both full duplex and half duplex FDD. Each radio frame is $Ts = 10\text{ ms}$ long and consists of 10 equally sized subframe of length 1ms. Then each sub frame is divided into two slots each of length 0.5ms.

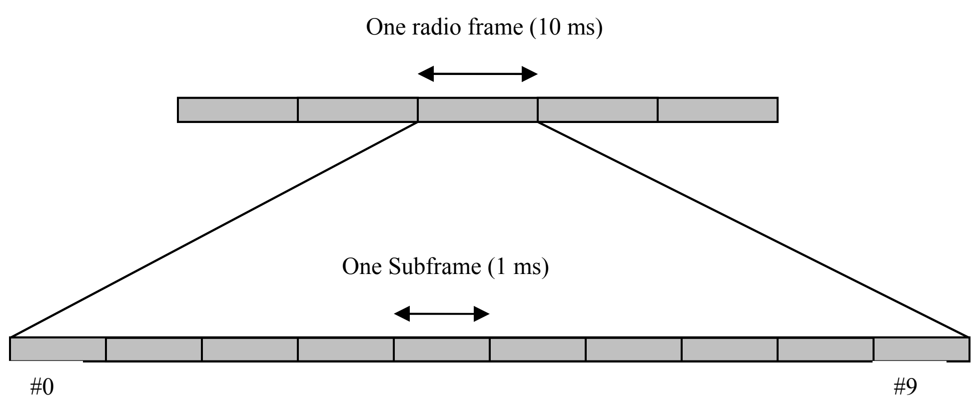

Figure 2.1 LTE Frame Structure [2]

2.2 Physical resource block

Each slot in a sub frame is represented by a recourse grid of $N_{\mathrm{RB}}^{\mathrm{UL}} * N_{\mathrm{sc}}^{\mathrm{RB}}$ sub carriers and $N_{\mathrm{symb}}^{\mathrm{UL}}$ SC-FDMA symbols. The resource grid is illustrated in Figure 2.2. Recourse block consists of 12 sub carriers and seven or six symbols depending upon the length of cyclic prefix in 1 time slot. Thus each resource block consists of 12 * 7=84 resource elements in case of normal cyclic prefix and 12 * 6=72 resource elements in case of extended cyclic prefix [2].

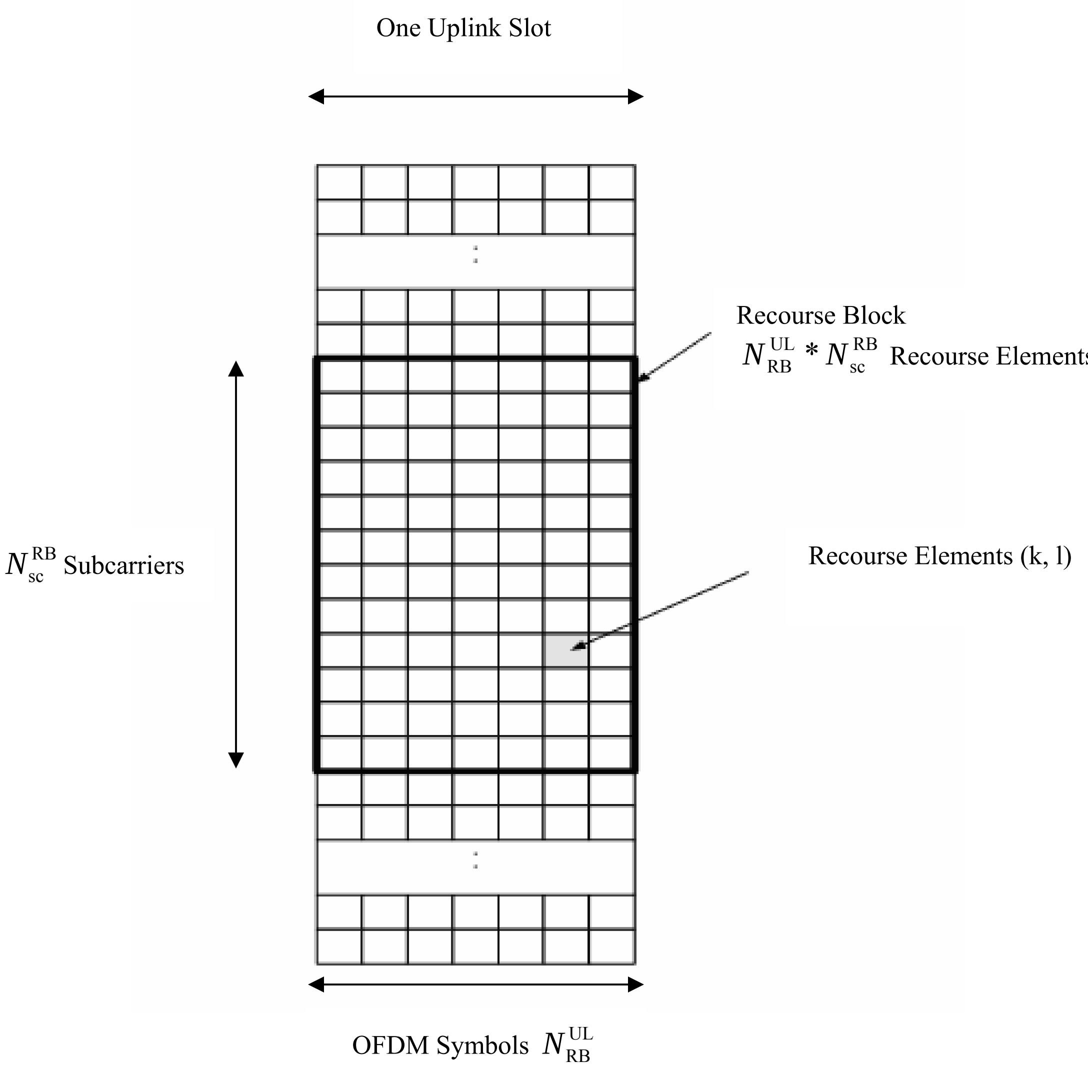

Figure 2.2 Physical Resource Block [2]

2.3 Downlink

LTE downlink transmission is based on Orthogonal Frequency Division Multiplex (OFDM). The basic LTE downlink physical resource can thus be seen as a time frequency resource grid. The minimum number of recourse blocks for downlink transmission consists of 6 RBs up to maximum of 110. This corresponds to bandwidth from 1.4 MHz to 20 MHz.

2.4 Uplink

Uplink transmition is based on DFTS-OFDM transmition which considers the power efficiency for UEs. DFTS-OFDM or SC-FDMA is low peak to average power ratio (PARP) transmition scheme that allows for flexible bandwidth assignment. The LTE uplink transport channel processing is different from downlink. Uplink transport channel processing does not define transmit diversity and spatial multiplexing. In addition, there is no explicit multi antenna mapping functions defined for the processing of the uplink transport channel.

2.5 Multiple Access Technique for LTE

2.5.1 OFDM

The basic principle of OFDM is to implement multi carrier transmition by dividing the signal with long duration time i.e. high data rate data stream into number of lower rate streams. The streams are sent simultaneously in parallel, which is less sensitive to channel fading as compare to one which is sent in series. Streams then mapped to large number of sub carriers with carrier spacing of 15KHz. This technique is implemented in both uplink and downlink.

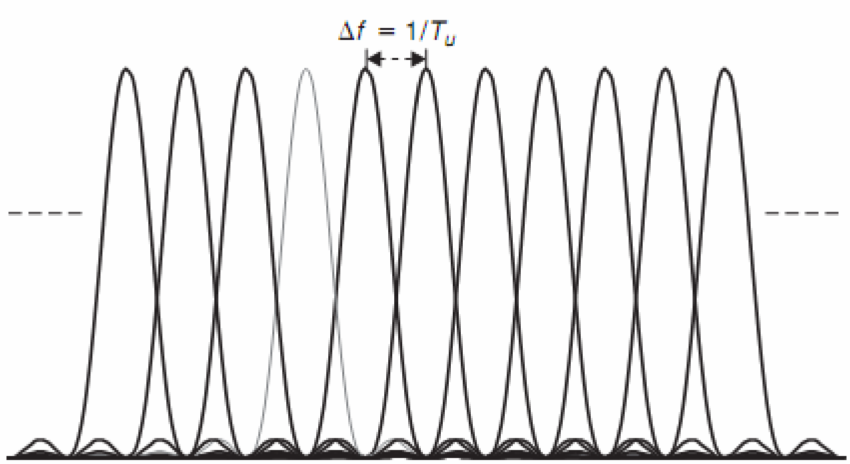

Figure 2.3 Sub Carrier Spacing [2]

The main advantage of OFDM is to remove ISI (Inter Symbol Interference) between OFDM symbols. This is usually done by adding cyclic prefix to the OFDM symbol before transmition. The disadvantage of OFDM is the frequency offset added due to doppler effects which makes subcarriers not orthogonal. The frequency domain description of sub carriers is shown in the figure 2.3 with sub carrier spacing of Δf . The number of OFDM sub carriers and spacing depends upon the system requirement such as available bandwidth.

Two main methods of OFDM in LTE are frequency and time division based duplex arrangement. FDD communication in uplink and downlink take place in different frequency bands. On the other hand in TDD uplink and downlink communication take place in same frequency band but in separate non overlapping time slots.

2.5.1.1 OFDM implementation using IFFT/FFT

By fast Fourier transform processing we can implement OFDM which is more efficient and less complex. Consider the figure 2.4, the sequence of modulated symbols is converted in to parallel blocks of symbols. Which is then applied to size N inverse discrete fourier transform extended with zeros to length N, the size of IDFT is equal to 2^m for some integer m. For a 5Mhz bandwidth the number of sub carriers is 300, the size of IDFT be selected as 512 with sampling rate of F_s = 7.6Mhz where Δ f = 15KHz is the sub carries spacing in LTE. Resulting samples from IDFT output is converted into analog after serial to parallel conversion.

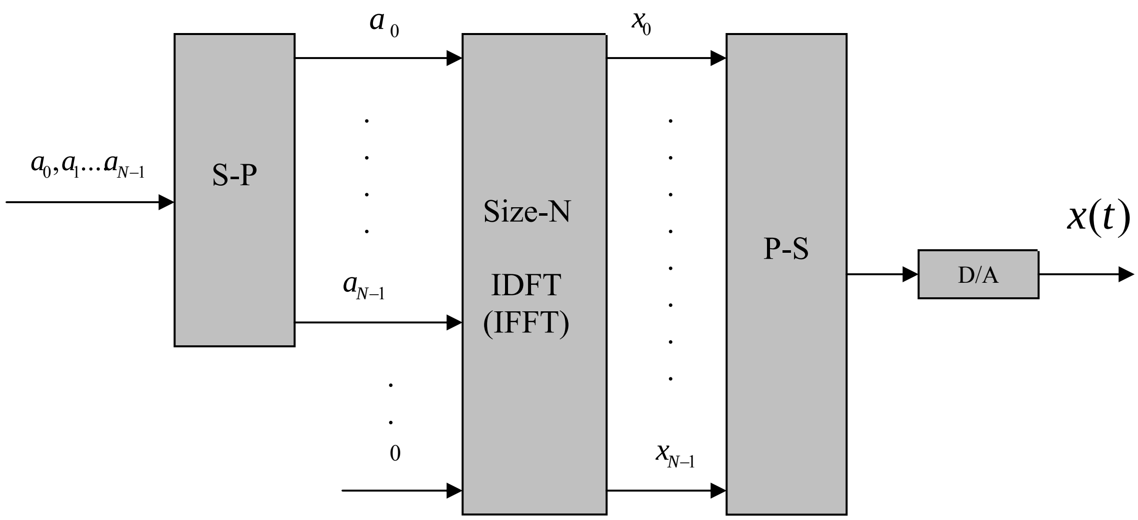

Figure 2.4 OFDM Modulation by mean of IFFT [2]

2.5.2 OFDMA

OFDMA (Orthogonal Frequency Division Multiple Access) do frequency multiplexing of OFDM signal for more then one user. All that were previously mentioned about OFDM also holds for OFDMA. Each user in an OFDMA system is usually given certain subcarriers during a certain time to communicate. Figure 2.5 show an example of OFDMA communication.

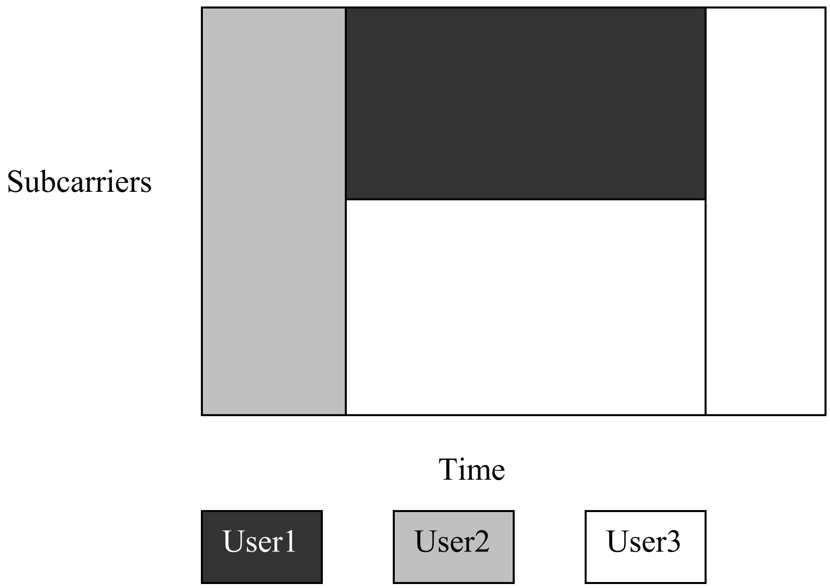

Figure 2.5 Example of an OFDMA Communication

2.5.3 Single-carrier FDMA (SC-FDMA)

Single-carrier FDMA (SC-FDMA) is a frequency division multiple access scheme. The main task of this scheme is to assign communication recourses to multiple users. The major difference to other schemes is that it performs DFT operation on time domain modulated data before going into OFDM modulation. 3GPP prescribes OFDMA for downlink transmission and SC-FDMA for uplink transmission in the long term evolution (LTE). SC-FDMA has similar performance and essentially the same overall complexity as OFDMA. But the main disadvantage of OFDMA is the low power efficiency of transmitted signal or in other words high peak to average power ratio (PAPR). To make UEs power efficient, they must have small variations in instantaneous power of transmitted signal. It also provides orthogonal access of system to multiple users simultaneously. The block diagram of SC-FDMA is shown in the figure 2.6.

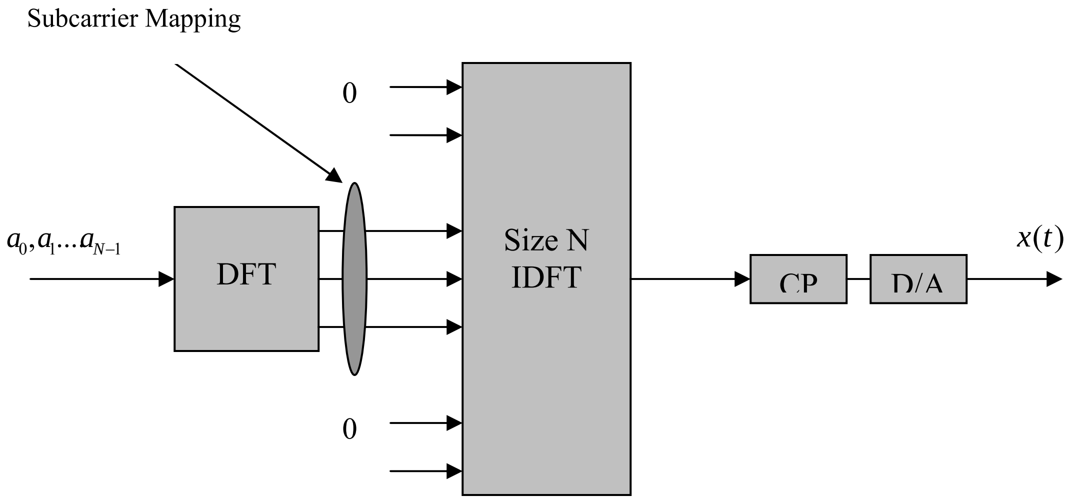

Figure 2.6 Basic structure of DFTS-OFDM transmission [2]

2.6 Receiver structure

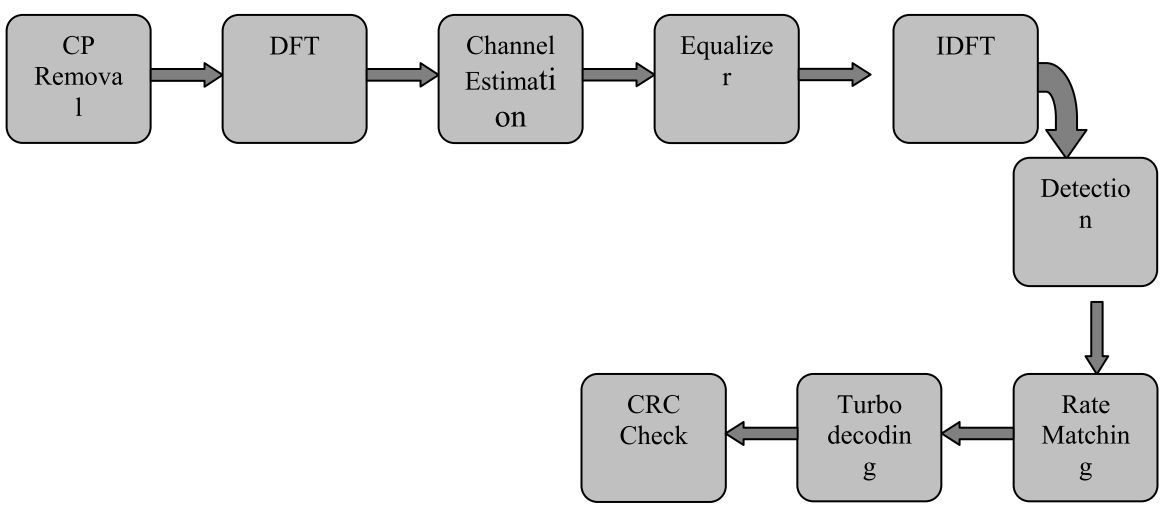

Figure 2.7 Receiver structure for uplink LTE

Receiver structure of simulation is shown in figure 2.7. At the receiver side cyclic prefixes will first be removed followed by a DFT to turn the time domain samples received into frequency domain samples. Channel estimation is performed on the received pilot symbols with equalizer. Channel estimation for SC-FDMA symbols are described in chapter 6. Equalization is more complex compare to downlink where subcarriers are independent and therefore every sub carrier will be assigned one equalizer where as in uplink the sub carriers are all dependent, so one equalizer is used for all subcarriers simultaneously, as shown in the figure 2.8.

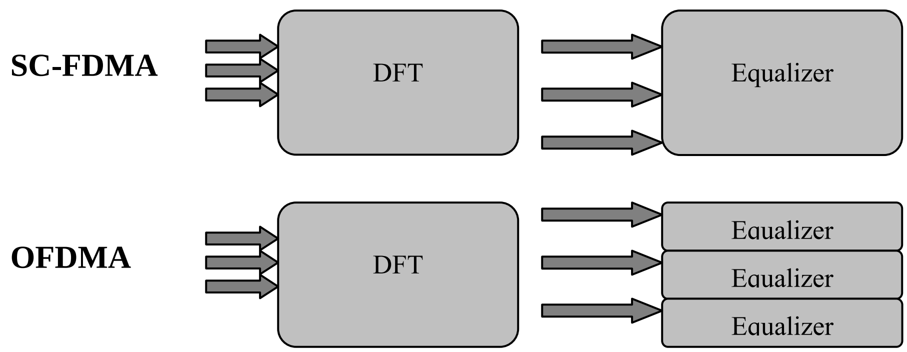

Figure 2.8 Equalizer for uplink and downlink [5]

Because SC-FDMA symbol has its modulated symbols contained in the time domain, an IFFT is needed before the turbo decoder. This is also the major difference compared to OFDMA, which is used on the downlink since OFDMA has its modulated symbols contained in the frequency domain and therefore the receiver does not need an IFFT.

The modulated symbols, QPSK, 16QAM, or 64QAM, will be demodulated into soft bits. A soft bit is when the symbols are demodulated into decimal values ranging from -1 to 1 depending on the certainty of the bit value. Where a negative value corresponds to a transmitted “1 bit” and a positive value corresponds to “0 bit”. A hard bit is when the symbols are demodulated into either 0 or 1 with respect to the certainty of the symbol actually being correct. Rate matching is performed on soft bits then turbo decoder will then use the output of rate matching as input. At the end CRC is checked for errors.

Uplink Channels 3

There are three types of data channels; physical channel, transport channel and logical channel as shown in the figure 3.1. All the user information and network control information is carried in uplink share channel UL-SCH. Other transport channel is random access channel. The purpose of RAC is to send request for transmission recourses. The transmission of user data and control information are carried by physical channel. There are three uplink physical channels. The thesis is limited to implementation of physical channel (PUSCH) and transport channel (UL-SCH) in Matlab according to the 3GPP specification. This chapter will explain Physical Uplink Shared channel (PUSH). The Uplink Shared Channel (UL-SCH) is explained in next chapter.

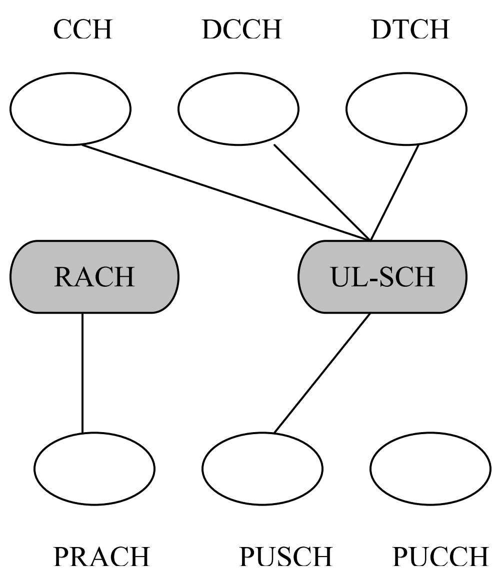

Figure 3.1 Uplinks Channels [5]

3.1 Uplink Physical Channels

LTE uplink supports three physical channels:

- Physical Random Access Channel (PRACH).
- Physical Uplink Shared Channel (PUSCH).
- Physical Uplink Control Channel (PUCCH).

Physical Random Access Channel (PRACH) carries random access preamble which contains cyclic prefix length, sequence length and also used to synchronize timings with the eNodeB. Physical Uplink Control Channel (PUCCH) carries the uplink control information which includes Hybrid Automatic Repeat Request (HARQ), channel quality indicators (CQI), MIMO feedback (Rank Indicator, RI; Precoding Matrix Indicator, PMI) and scheduling requests for uplink transmission. The Physical Uplink Shared Channel (PUSCH) carries user information and control information received on the uplink shared transport channel (UL-SCH). The steps involved in Physical Uplink Shared Channel processing are shown in figure 3.2 [15].

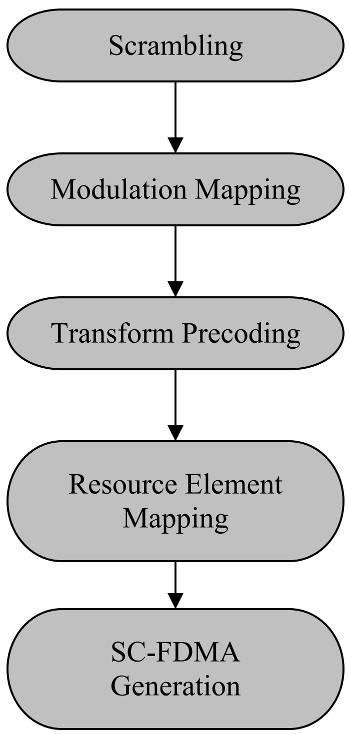

Figure 3.2 Physical Uplink Shared Channel processing [5]

3.1.1 Bit Level Scrambling

The bits delivered by rate matcher are multiplied by a pseudo random sequence. This will help to ensure that the receiver side decoding can fully utilized the processing gain provided by the channel codes [2]. Without scrambling of uplink signal the channel decoder at mobile terminal can match to the interfering signal inspite of desired signal .UE specific scrambling sequence are generated prior to modulation. Pseudo random sequence is defined by length 31 gold sequences $c(n)$ [14].

$$c(n) = \left(x_1(n+N_C) + x_2(n+N_C)\right) \bmod 2$$
$$x_1(n+31) = \left(x_1(n+3) + x_1(n)\right) \bmod 2$$
$$x_2(n+31) = \left(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\right) \bmod 2$$

Where $N_C = 1600$, the first m sequence x_1 is initialized with $x_1(0) = 1, x_1(n) = 0, n = 1,2,...,30$ and second m sequence is initialized by $c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{14} + \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\text{ID}}^{\text{cell}}$ [14].

3.1.2 Data Modulation

After scrambling the bits are mapped to complex modulation symbols. The supported LTE uplink modulation schemes include QPSK, 16QAM and 64QAM.

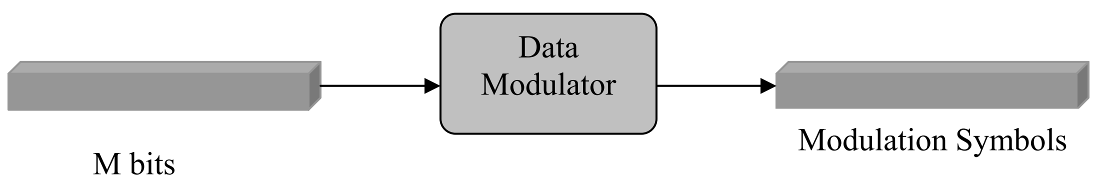

Figure 3.3 Data Modulation

3.1.3Transform Precoding

Transform Precoding corresponds to DFT operation in figure 3.2. The block of M modulation symbols from QPSK or 16QAM is applied to size M-DFT. In physical uplink shared channel (PUSCH), the size of the DFT Precoding corresponds to the number of scheduled subcarriers used for PUSCH transmission in an SC-FDMA symbol.

3.1.4 Resource element mapping

Recourse element corresponds to subcarrier mapping shown in figure 3.4. The output of the DFT is mapped to subcarriers assigned by scheduler in recourse block used by physical channel. Sub carrier block maps the frequency domain symbols to sub carriers. SC-FDMA system uses either distributive or localized mapping. But in uplink transmission LTE is limited to localized transmission, i.e. the output of DFT is mapped to consecutive inputs of IFFT. In the localized sub carrier mapping mode, the modulation symbols are assigned to M adjacent sub carriers. In the distributed mode, the symbols are equally spaced across the entire channel bandwidth. In both modes, the IDFT in the transmitter assigns zero amplitude to the N − M unoccupied sub carriers [5].

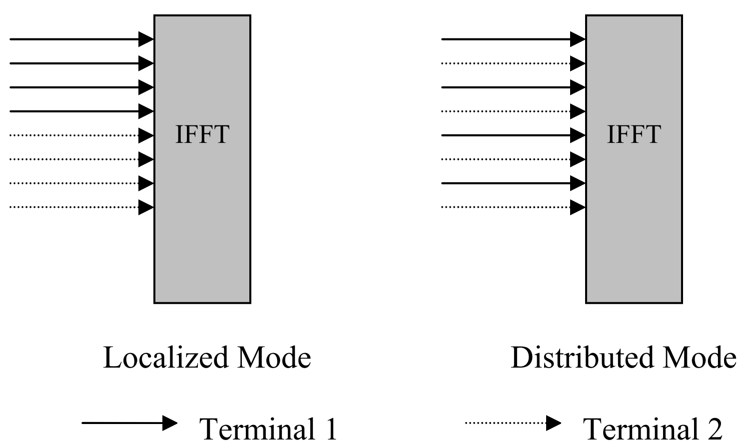

Figure 3.4 Subcarrier Mapping [5]

3.1.5 SC-FDMA signal generation

Generation of complex baseband signal involve four steps N-IDFT, parallel to serial conversion, addition of cyclic prefix and digital to analog conversion. The result is a continuous signal, shown in figure 3.5.

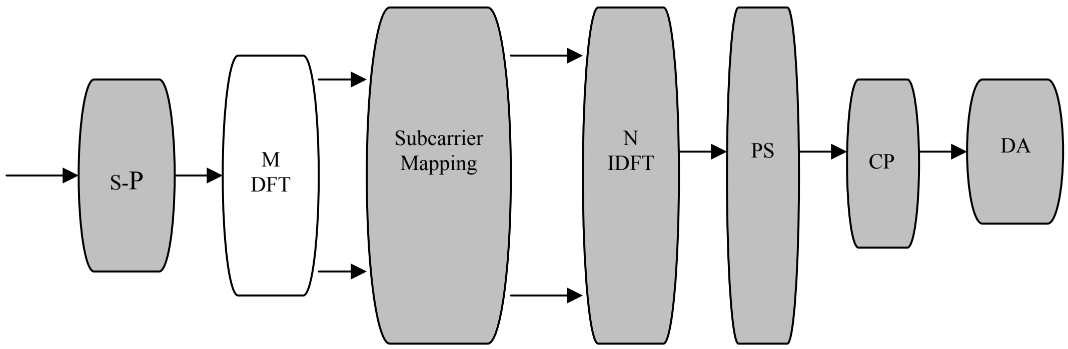

Figure 3.5 SC-FDMA Symbol Generation[5]

- N-point IDFT

The output of the sub carrier mapping is then applied to consecutive inputs of a size N inverse DFT where N >M and remaining inputs of IDFT are set to zero, the output of the IDFT will be a signal with 'single-carrier' properties, i.e. a signal with low power variations. If the size of both DFT and IDFT are same then IDFT just cancel the effect of DFT.

- Cyclic prefix

Cyclic prefix is inserted for each transmitted block. The CP is a copy of the last part of the block as shown in Figure 3.6, in order to provide a guard time to prevent inter block interference (IBI) due to multipath propagation.

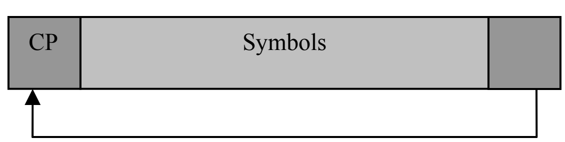

Figure 3.6 Cyclic prefix Insertion

- Parallel to Serial

The parallel to serial converter places time domain sequence suitable for modulating a radio frequency carrier and transmission to the receiver. [5]

Uplink Transport Channel Processing 4

Physical layer communicates with higher layers by mean of transport channel. The principle of transferring data to physical layer is similar to WCDMA/HSPA and characteristics of transport block for LTE is same as it is in HSPA

4.1 LTE uplink transport channel

The following steps are defined for LTE uplink transport channel processing, can be outlined according to figure 4.1.

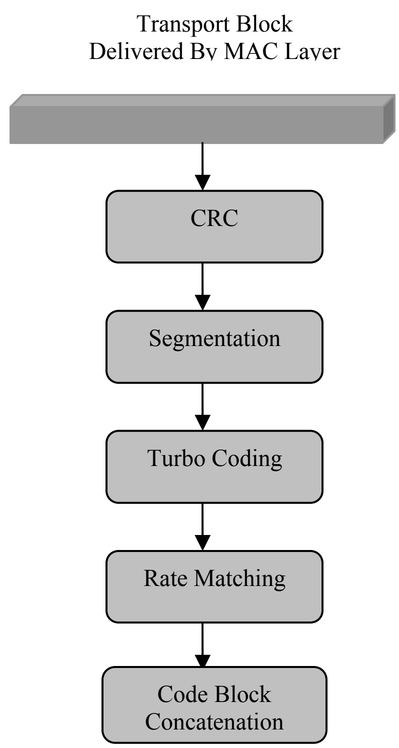

Figure 4.1 LTE uplink transport channel processing [2]

4.1.1CRC Insertion

Starting with the 24 bit CRC insertion at the end of transport block as shown in figure 4.2. The main purpose of CRC is to detect errors in decoded transport block. After the detection of errors, hybrid ARQ protocol will be triggered for requesting retransmissions.

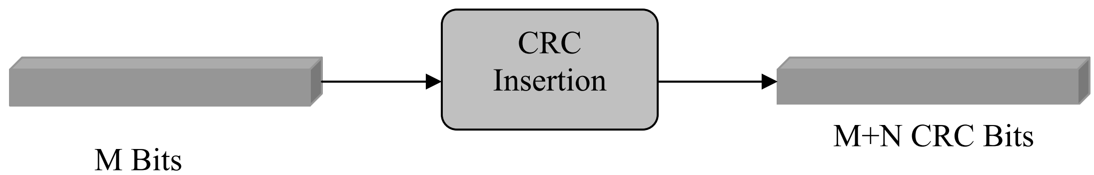

Figure 4.2 CRC Insertion [2]

4.1.1.1 CRC Calculation

The input data for CRC calculation is divided by a polynomial, the remainder of this division is appended with input data. At the receiver side the received bits are divided by the same polynomial if the remainder is zero then the transmition was successful. If the result is not equal to zero, an error occurred during the transmission. In uplink two types of polynomials are used for CRC generation which is defined in 3GPP specification TS36.212 [13].

$$g_{\mathrm{CRC24A}}(D) = [D^{24} + D^{23} + D^{18} + D^{17} + D^{14} + D^{11} + D^{10} + D^{7} + D^{6} + D^{5} + D^{4} + D^{3} + D + 1]$$

$$g_{\mathrm{CRC24B}}(D) = [D^{24} + D^{23} + D^{6} + D^{5} + D + 1] \text{ for a CRC length } L = 24$$

CRC 24A is appended to the data, if data is divided in blocks then each block is also appended with CRC 24B. Code block segmentation is explained in next step.

4.1.2 Code Block segmentation

There is a limit for internal interleaver of turbo coding, which is defined only for specific range of block size. The range is between 40 to 6144 bits of block size, if the block size including the CRC exceeds the limit then block segmentation is applied before Turbo coding. Block segmentation will divide the transport block into smaller segments that match the size of the set of code block size defined for turbo coder.

The size of each code block must be equal to the defined code block, to achieve that filler bits are added at the head of the first code block. These filler bits are also needed if there is no code block segmentation that is if the code block size is in the range.

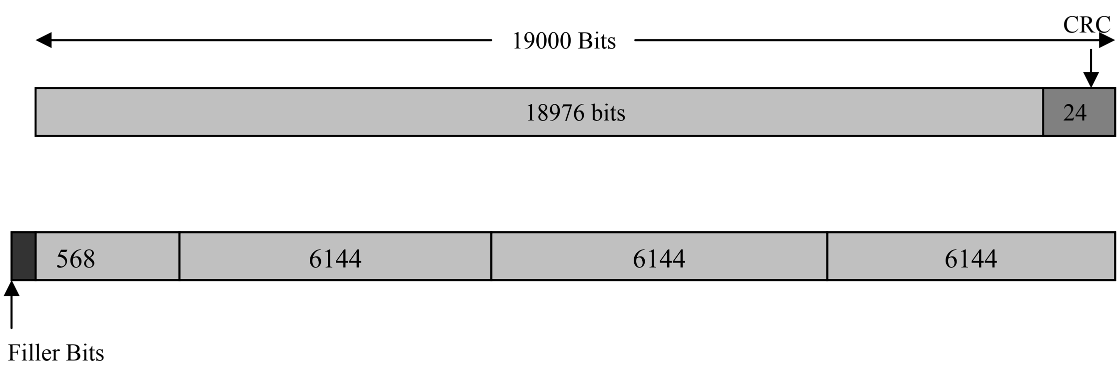

Figure 4.3 Transport Block Segmentation [1]

Figure 4.3 shows how the block is segmented, additional CRC is calculated for each block and is appended. This will help early detection of correctly decoded code block and early termination of the iterative decoding of that code block. If there is only one code block then there is no need for additional CRC [13].

4.1.3 Turbo Coding

4.1.3.1 Background of Turbo Coding

Error will occur as we transmit the code over a noisy channel. To achieve lossless transmission redundancy need to be introduced and that is done by channel coding to represent the information in a manner that minimizes the error probability in the coding. Shannon proved in 1948 that error free communication is possible if the transmition rate less is then the channel capacity. Turbo codes are introduced by Berrou et al which can achieve the capacity within a fraction of decibel (dB) with well designed interleaver. Achieving the capacity is not a problem for different coding approaches as the length of code increases. But the problem is complexity in encoding and decoding. Berrou et al showed that both capacity and low complexity can be achieved by introducing interleaver between two parallel concatenated convolutional codes.

Turbo coding is one of the major block of LTE uplink channel. LTE turbo encoder is shown in the figure 4.4 in which two recursive convolutional encoders are used with overall rate of 1/3 which includes 12 tail bits for trellis termination. The transfer function of encoder is [13]:

$$G(D) = \left[1, \frac{g_1(D)}{g_0(D)} \right],$$

where

$$g_0(D) = 1 + D^2 + D^3,$$

$$g_1(D) = 1 + D + D^3.$$

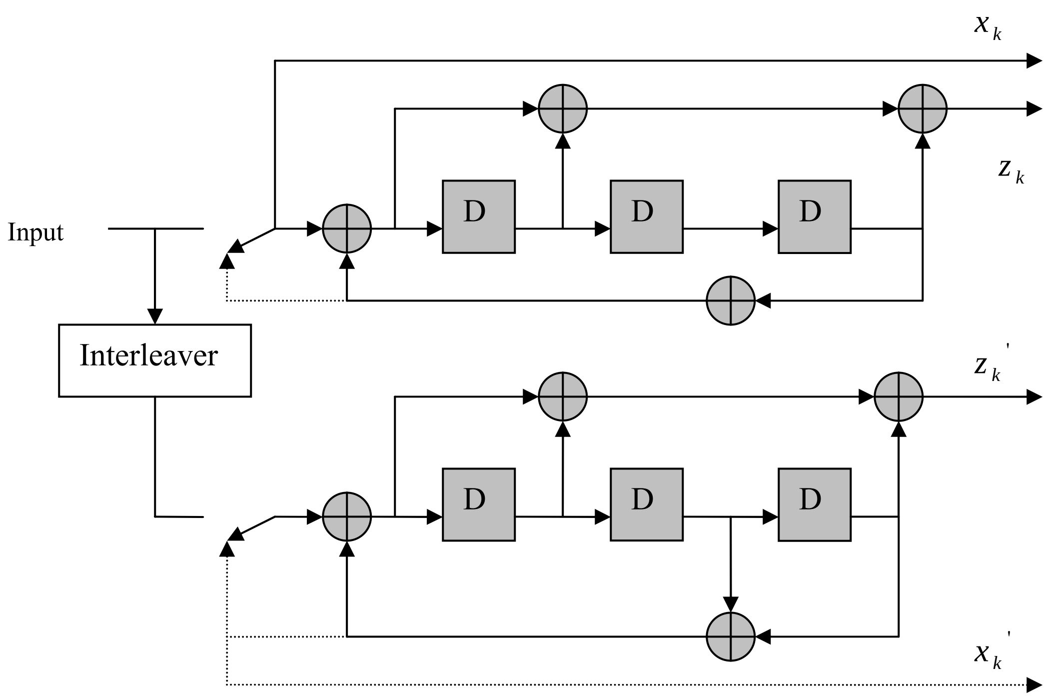

Figure 4.4 Turbo Coding [13]

The data stream is fed directly into the first encoder where as for second encoder the input is interleaved. Both the encoders have coding rate 1/2, the output of second encoder x'_k is same as output of first encoder x_k. Thus the rate of the turbo encoder is 1/3.

4.1.3.2 Contention free QPP Interleaver

The internal interleaving of turbo coding is based on quadratic permutation polynomials QPP interleaver according to the function:

$$C(i) = f_1.i + f_2.i^2.\text{mod}\,K$$

Where i is the index of the bit at the output of the interleaver, $C(i)$ is the index of same bit at the input of the interleaver, K is the size of code block and values of f_1 and f_2 are coefficients that define permutation and they depends on the code block size [13].

To meet the requirements of high data rate in LTE it's important to have low complexity interleaver that facilitates the high throughput turbo decoding. The latency added by the interleaver lower down the data rate, as the parallel decoders try to access the data block at the same time. To overcome this LTE uses contention free QPP interleaver that is suitable for parallel decoding of turbo codes without a risk for contention when accessing the interleaver memory [6].

4.1.4 Rate Matching

The rate matching for transport channel is described in [13]. The task of the rate match is to extract the bits from the turbo block coded bits and the number of extracted coded bits depends upon the recourses allocated by the scheduler.

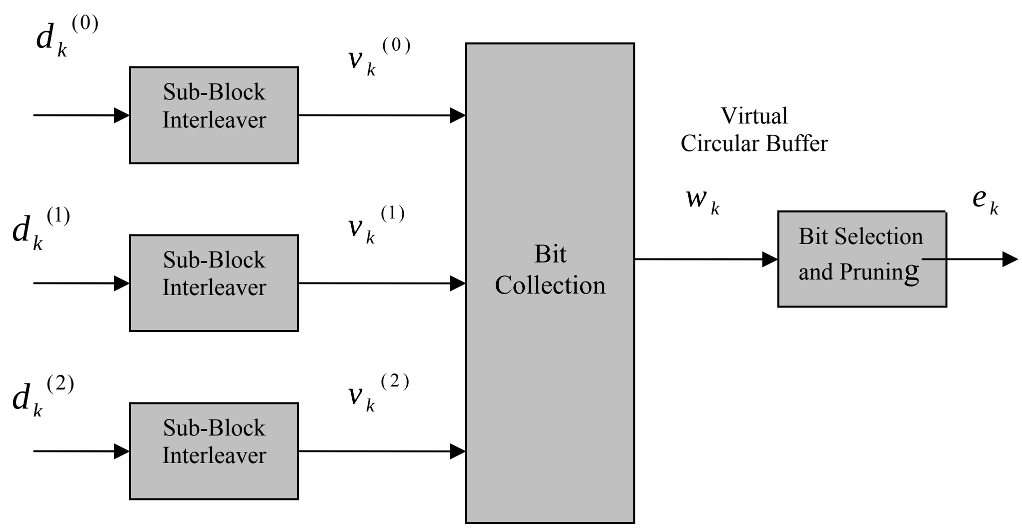

Figure 4.5 Rate Matching [13]

As shown in the figure 4.5 the output from the turbo encoder consists systematic bits $d_k^{(0)}$, first parity bits $d_k^{(1)}$ and second parity bits $d_k^{(2)}$, which are interleaved separately. Followed by collection of bits and generation of circular buffer.

4.1.4.1 Interleaving

Another important component of digital communication is interleaving. The goal of interleaving is to take care of errors that occur in bursts. This is done by shuffling the bits in the message after coding, resulting in scattering of bursty errors when the bits are de interleaved before coding.

Each stream, $d_k^{(0)}$, $d_k^{(1)}$ and $d_k^{(2)}$, is rearranged with its own subblock interleave, forming $v_k^{(0)}$, $v_k^{(1)}$ and $v_k^{(2)}$ respectively. The subblock interleaver described in [13] is based on row column permutation obtained by reading bits column by column in rectangular matrix. The matrix contain 32 columns and $r = \lfloor D/32 \rfloor$ rows in each sub block interleaver, dummy bits are padded if matrix is not full. Where D is total number of bits in transport block.

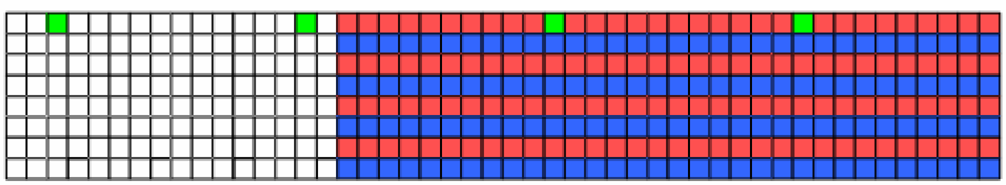

Figure 4.6 LTE turbo code rate matching [7]

32 columns in each subblock interleaver as shown in the figure 4.6, The first 32 columns in white represents the systematic bits after subblock interleaving, while the remaining 64 columns represent bit by bit interlaced columns of the permuted Parity 1 and Parity 2 streams in red and blue respectively. Green cells mark starting points of redundancy versions defined for RM [7].

4.1.4.2 Bit selection and pruning

Redundancy Versions (RV) are defined in LTE to support HARQ. Each RV is defined as starting point, RV 0, 1, 2, 3 set the 3, 27, 51 and 75 columns respectively. For a desired code rate of operation with a particular RV setting, the number of bits to be selected for transmission is passed to the RM. The bit selection step simply read out the total number

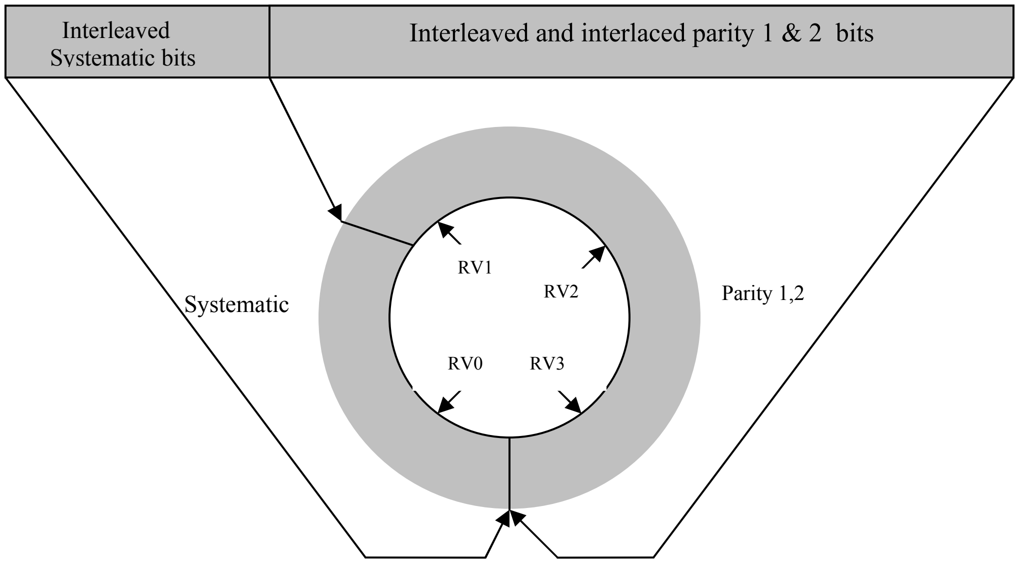

Figure 4.7 Circular Buffer for Rate Matching [1]

of bits available for the transmission of one transport block. When the end of the buffer reached, then the reading continues by wrapping around to the beginning of the buffer (hence the term circular buffer), as shown in figure 4.7 [7].

If the total no of bits that delivered by the coder is larger then the available bits for transmition then HARQ put his part to extract a subset of coded bits resulting to higher code rate. Alternatively if the total number of bits are less then the number of bits to be transmitted, the functionality of circular come across where code bits will repeat resulting into a smaller code rate.

4.1.5 Code Block Concatenation

The code block concatenation only needs to be done when the number of code blocks is larger than one for the turbo coding case. We note that the code block concatenation consists of sequentially concatenating the rate matching outputs for the different code blocks [13].

Channel Estimation 5

In this chapter I will describe how the reference signal is generated in LTE uplink, channel model used and channel estimation techniques. Channel estimation is important part of receiver design in mobile communication systems. To recover the transmitted signal correctly, the behavior of channel must be estimated. For perfect recovery, receiver has to keep track of the varying radio channel.

5.1 Uplink reference signal

5.1.1 Classification of CE

In general, both iterative and non iterative CE techniques can be divided into three categories such as blind CE, and semi-blind CE and pilot based CE.

5.1.1.1 A blind CE

Blind CE requires no pilot sequence. They exploit certain underlying mathematical information regarding the type of data being transmitted. These methods are bandwidth efficient but still have high bit error rate. One of the popular methods is decision directed algorithms which rely upon the demodulation and detected signal at the receiver to reform the transmitted signal [10].

5.1.1.2 Semi-blind CE

Large number of pilot symbols is required for large number of channel coefficients which results in a decrease of data throughput. Which result in a decrease of data throughput. To avoid it, semi blind CE methods are used with fewer pilot symbols. To improve the system bandwidth superimposition of pilot and data symbols are made. But in superimposed training sequence scheme, there is disadvantage due to the interference of information data [10].

5.1.1.3 Pilot assisted Channel Estimation

In LTE uplink pilot symbols are time multiplexed with data sequence. These pilot symbols allow the receiver to extract channel attenuations and phase rotation estimates for each received symbol, facilitating the compensation of Channel fading envelope and phase [10].

Training symbols are transmitted at certain position of the OFDMA frequency time pattern. Increase of training sequence improve the accuracy of CE, but at the same time degrades the system efficiency. In LTE uplink, the pilot symbols are placed on fourth symbol of each slot as shown in figure 5.1, two pilot symbols in a frame.

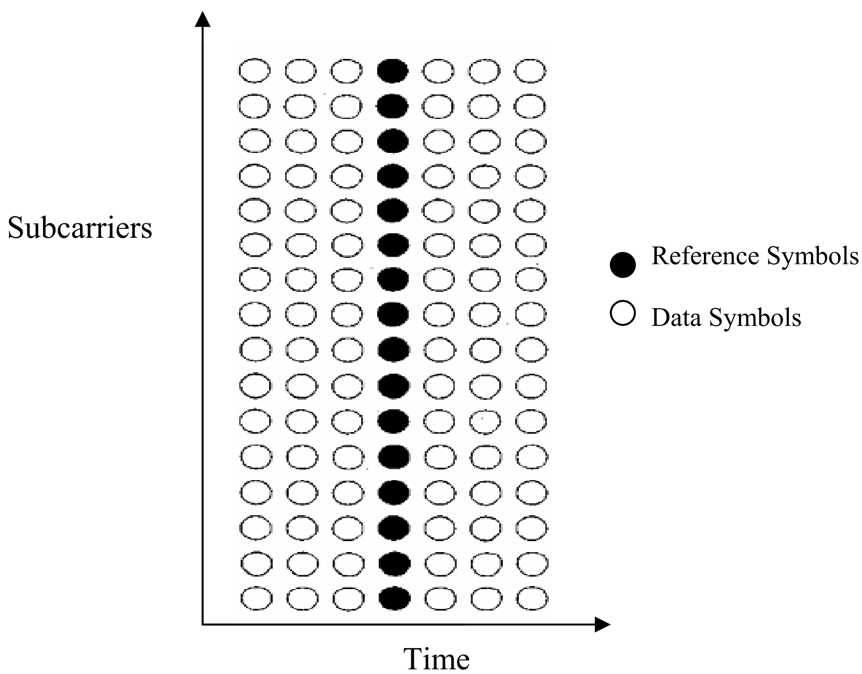

Figure 5.1 Positions of data and pilot symbols.

5.1.2 Uplink demodulation reference signal

For channel estimation, reference signal enables coherent demodulation at the receiver. This signal is called demodulation reference signal (DRS). Generated reference signal is different from downlink due to the low power variations for uplink transmition. Uplink reference signals are time multiplexed with other uplink transmition from same mobile terminal. The signal is transmitted within the fourth symbol of each uplink slot, which means that there are two reference symbols in each subframe.

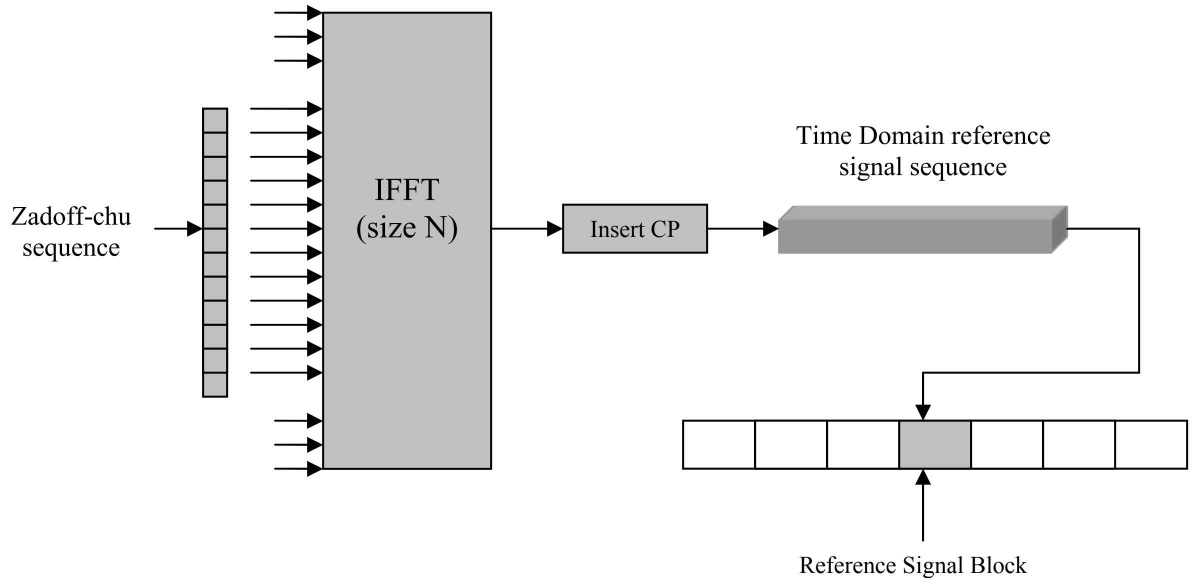

Figure 5.2 Uplink demodulation reference signal [2]

As shown in the figure 5.2 uplink reference signal is applied to consecutive inputs of an OFDM modulator. After modulation cyclic prefix is then inserted similar to other transmition. For uplink reference signal, it should have limited power variations in frequency and time domain. Zadoff-chu sequences have these properties which can be expressed as:

$$r_{u,v}^{(\alpha)}(n) = e^{j\alpha n}\bar{r}_{u,v}(n), \quad 0 \le n < M_{\mathrm{sc}}^{\mathrm{RS}}$$

Where $M_{\mathrm{sc}}^{\mathrm{RS}} = mN_{\mathrm{sc}}^{\mathrm{RB}}$ is the length of the reference signal sequence and $1 \le m \le N_{\mathrm{RB}}^{\max,\mathrm{UL}}$.

5.1.3 Base Reference sequence

For $M_{\mathrm{sc}}^{\mathrm{RS}} \ge 3N_{\mathrm{sc}}^{\mathrm{RB}}$, the base sequence $\bar{r}_{u,v}(0),...,\bar{r}_{u,v}(M_{\mathrm{sc}}^{\mathrm{RS}}-1)$ is given by:

$$\bar{r}_{u,v}(n) = x_q(n \bmod N_{\mathrm{ZC}}^{\mathrm{RS}}), \quad 0 \le n < M_{\mathrm{sc}}^{\mathrm{RS}}$$

Where the q^{th} root Zadoff-Chu sequence is defined by

$$x_q(m) = e^{-j\frac{\pi q m(m+1)}{N_{\text{ZC}}^{\text{RS}}}}, \quad 0 \le m \le N_{\text{ZC}}^{\text{RS}} - 1$$

Where q given by:

$$q = \lfloor \bar{q} + 1/2 \rfloor + v \cdot (-1)^{\lfloor 2\bar{q} \rfloor}$$
$$\bar{q} = N_{\text{ZC}}^{\text{RS}} \cdot (u+1)/31$$

The length $N_{\text{ZC}}^{\text{RS}}$ of the Zadoff-Chu sequence is given by the largest prime number such that $N_{\text{ZC}}^{\text{RS}} < M_{\text{sc}}^{\text{RS}}$ [14]

5.1.4 Phase rotation of basic sequence

UE will transmit reference signal with in a cell. Other UEs residing in neighboring cells also send reference signals. There will be a chance of interference of reference signal between both of UEs in different cell when they transmit the signal simultaneously. To cater this problem, different values of u in above formulas is used to generate different sequences with in the set of zedoff-chu sequences of length M_ZC. These sequences are the phase rotation of basic sequence. Applying the linear phase rotation in frequency domain is equivalent to applying a cyclic shift in time domain. These reference signals typically have non zero mutual correlation. So the phase rotated reference signals are completely orthogonal and causes no interference to each other. The cyclic shift is defined in 3GPP specification as [14]:

The cyclic shift α in a slot n_{s} is given as $\alpha = 2\pi n_{\text{cs},\lambda}/12$ with

$$n_{\text{cs}} = \left(n_{\text{DMRS}}^{(1)} + n_{\text{DMRS},}^{(2)} + n_{\text{PN}}(n_{\text{s}})\right) \bmod 12$$

Where the values of $n_{\text{DMRS}}^{(1)}$, $n_{\text{DMRS}}^{(2)}$ is according to the parameter cyclic Shift provided by higher layers, for simplicity it is set to zero. The quantity $n_{\text{PN}}(n_{\text{s}})$ is given by:

$$n_{\text{PN}}(n_{\text{s}}) = \sum_{i=0}^{7} c(8N_{\text{symb}}^{\text{UL}} \cdot n_{\text{s}} + i) \cdot 2^i$$

Where the pseudo-random sequence $c(i)$ initialized with $c_{\text{init}} = \left\lfloor \frac{N_{\text{ID}}^{\text{cell}}}{30} \right\rfloor \cdot 2^5 + f_{\text{ss}}^{\text{PUSCH}}$ at the beginning of each radio frame [14].

5.1.5 Reference signal assignment

The base reference signal $\bar{r}_{u,v}(n)$ are grouped together for assigning them to cells, where $u \in \{0,1,...,29\}$ is the group number and v is the base sequence number within the group. For transmition bandwidth of five or less recourse blocks, we have one base reference signal (v= 0) sequence of length less or equal to 60.Two base reference signals (v=0, 1) sequence of length larger or equal to 72 for transmission bandwidth of six or more.

5.2 Channel Model

The realistic channel model for wireless communication is essential for the analysis, design and deployment of the communication systems. The correct knowledge of the mobile channel models are significant for testing, optimization and performance improvements signal processing algorithms. Wireless communication has the phenomenon named multi path fading. This is because of reflection from objects when the signal is transmitted in the channel. As a result signal reaches the receiver by two or more paths with some delay as shown in the figure 5.3.

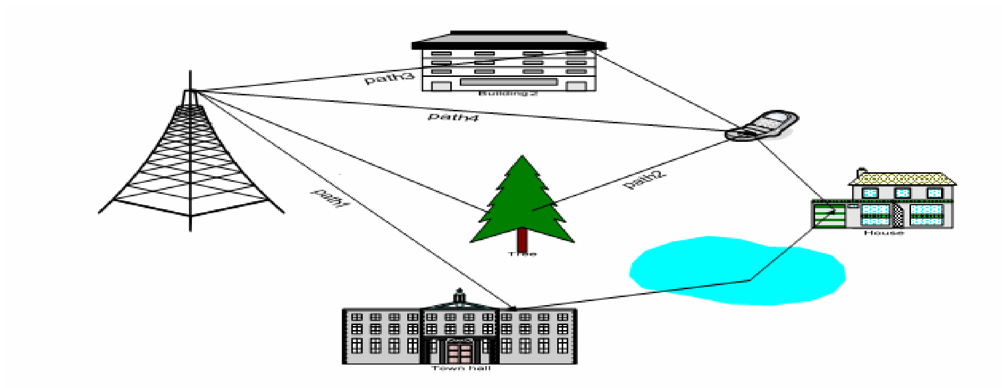

Figure 5.3 Channel Model

Multipath propagation will be modeled as

$$y(n) = h_1 s(n - t_1) + h_2 s(n - t_2) + ... + h_T s(n - t_{|T}) + v(n)$$

Where y(n) is the received signal, h_T are the channel coefficient, $s(n - t_{|T})$ is delayed version of transmitted signal $s(n)$ due to reflection, and $v(n)$ is additive noise. Noise is usually measured by SNR (Signal to Noise Ratio), which is defined as the ratio of the received signal power to the power of noise within the bandwidth of the transmitted signal $s(n)$. To make the simulation close to reality some kind of channel model should be chosen. There are different channel models like Rayleigh fading channel and Rician. In Rayleigh fading channel, there is no line of sight between transmitter and receiver and channel taps are independent where as in Rician fading channel, the fading dips are low due to presence of line of sight.

5.2.1 Multipath Propagation Channel

The received signal affected by different propagation paths, these paths are called channel taps. Which cause different delayed versions of transmitted signal as described in equation. The intensity of a received signal through multi path as a function of time delay called power delay profile (PDP). PDP is an important channel characteristic parameter which is necessary for receiving techniques such as Minimum Mean-Square Error (MMSE) channel estimation. Researchers try to obtain the information of PDP through extensive field measurements and numerical simulations but these measurements hardly provide accurate PDP information since the radio propagation environment is always changing [9].

5.2.2 Propagation aspects and Parameters

To model the communication channel the behavior of the multipath channel must be identified. The concepts of Doppler spread, coherence time, delay spread and coherence bandwidth describe various aspects which helps in channel modeling.

5.2.2.1 Delay Spread

The multiple copies of transmitted signal are received propagating at different paths. The signal propagating at shorter path reaches the receiver earlier compare to the signals at other paths. These non simultaneous arrivals of signal cause the spread of the original signal in time domain. This spread is called delay spread.

5.2.2.2 Coherence Bandwidth

When channel in frequency domain is studied then coherence bandwidth is of concern. The frequency interval in which the amplitudes of all frequencies of transmitted signal are correlated is known as coherence bandwidth. A multipath channel can be categorized as frequency flat fading or frequency selective fading .

Frequency flat fading: When all the frequency components of the signal will experience the same amount of fading.

Frequency selective fading: When different frequency components will undergo different amount of fading.

5.2.2.3 Doppler Spread

The Doppler spread arises due to the motion of mobile terminal. As the UE moves the length of path between transmitter and receiver changes, as a result a Doppler frequency shift is induced on the signal.

5.2.2.4 Coherence Time

The time over which the characteristics of a channel do not change significantly is termed as coherence time. The reciprocal of the Doppler shift is described as the coherence time of the channel.

5.3 ITU Multipath Channel Models

International Telecommunication Union (ITU) proposed multipath channel models for the development of 3G IMT 2000 group of radio access systems which are similar in structure to the 3GPP multipath channel models. ITU proposed set of test environments that cover all the scenarios according to user mobility. These models greatly helped system designers and network planners for evaluating performance. In my work I used ITU standard channel models for pedestrian and vehicular environments [17].

5.3.1 ITU Pedestrian A, B

I used both Pedestrian A and Pedestrian B channel models in my work. The mobile speed considered to be 3km/h in each of these cases .The number of taps incase of Pedestrian A model is 4 while Pedestrian B has 6 taps. The average powers and relative delays for the taps of multipath channels based on ITU recommendations are given in table 5.1.

Pedestrian-A			Pedestrian-B	
Tap No	**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 5.1 ITU Pedestrian Channel Models

5.3.2 ITU Vehicular Channel models

For vehicular environments ITU proposed channel models vehicular A and vehicular B are used. Mobile speed considered for both models is 30km/h and 120km/h respectively. The average power and the relative delay for multipath channels based on ITU recommendations are given in table 5.2.

Vehicular –A			Vehicular –B	
Tap No	**Relative Delay(ns)**	**Average Power(dB)**	**Relative Delay(ns)**	**Average Power(dB)**
1	**0**	**0**	**0**	**-2.5**
2	**310**	**-1**	**300**	**0**
3	**710**	**-9**	**8900**	**-12.8**
4	**1090**	**-10**	**12900**	**-10**
5	**1730**	**-15**	**17100**	**-25.2**
6	**2510**	**-20**	**20000**	**-16**

Table 5.2 ITU Vehicular Channel models

5.4 General CE procedure

First the channel response is determined on symbols consisting of pilot symbols using CE techniques like Squares (LS) and Minimum Mean Squares (MMSE) estimates. After that interpolation is used to determine the channel response at the data sub carriers. The interpolators used for the purpose of estimation are linear, second order and cubic .In this chapter, I attempt to give an overview of these estimation Pilot assisted techniques with a reference to LTE uplink structure described in chapter 2.

5.5 Channel Estimation Techniques

5.5.1 Least Square (LS) channel estimator

The LS estimator is a basic 1D channel estimator, which is described in [10] and [11]. LS CE tries to determine the channel impulse response from known transmitted pilot symbols. We assume that all the sub carriers on short blocks are occupied by pilots, and we set d as a group of pilot symbols. D is a matrix with the elements of d on its diagonal.

$$D = \begin{bmatrix} d(0)\cdots\cdots 0 \\ 0\ldots d(1)\cdots 0 \\ \vdots \\ 0\cdots\cdots d(n-1) \end{bmatrix}$$

An LS estimator is trying to find the channel impulse response h_{LS} that minimizes the square error

$$e = \left| y - DFh_{LS} \right|$$

Where h_{LS} is

Where F is the DFT matrix and y is the received signal. In order to minimize

$$h_{LS} = \arg_{h_{LS}} \min(y - DFh_{LS})^H (y - DFh_{LS})$$

$$h_{LS} = QFDY \quad \text{where Q is } Q = (F^H D^H DF)^{-1}$$

This expression can be transferred to the frequency domain by taking the DFT of h_{LS}

$$H_{LS} = Fh_{LS} = FQF^H D^H y$$

$$H_{LS} = D^{-1} y$$

The LS channel estimation simplifies to divide the received pilot symbols with the known pilot symbols.

5.2.2 LMMSE Channel Estimation

Another technique to find the channel impulse response (CIR) is minimum mean square error MMSE which is computationally complex compare to LS CE. But have better performance than LS. This method intends to minimize the mean square error between the exact and estimates CIR. In this section I will discuss linear minimum mean square estimator (LMMSE).The LMMSE calculated the channel impulse response that minimizes the mean squared error as [11]:

$$e = \left| h - Gh_{LS} \right|^2$$

MMSE estimation is obtained by filtering of LS estimate by G .

$$h = G \ h_{LS}$$

$$G = R_{hh_{LS}} (R_{h_{LS}} + \sigma_N{}^2 I)^{-1}$$

From the above equation it can be seen that in order to find the LMMSE estimator we have to determine the autocorrelation matrices. Where $R_{hh_{LS}}$ $R_{h_{LS}}$ is the cross correlation and auto correlation matrix respectively given by $R_{hh_{LS}} = E\{hh_{LS}{}^H\}$, $R_{h_{LS}} = E\{h_{LS} h_{LS}\}$ and $\sigma_N{}^2$ is noise variance.

Implementation 6

This chapter will explain the different parts of simulator written in MATLAB and how they are connected. In earlier chapters of the report different modules are explained in detail, know this chapter will explain how they are interconnected in the simulator.

6.1 Implementation

6.1.1 Implementation choices

The MATLAB programming language was chosen for several reasons. The first is due to reduced development time and built in excellent mathematics and engineering functions. The second main reason is due to the simulator developed by Vienna University of Technology for LTE downlink [16]. That simulator helped to use the functions that are same for Uplink.

6.1.2 Usage and Features

The usage of simulator is by installing MATLAB with version higher then 9.

- Generating a UE signal for LTE uplink.
- Testing environment for uplink transmition.
- Estimation of channel.

6.1.3 Interfaces

Figure 6.1 explains the flow of simulation and the interfaces of simulator is defined as:

LTE_load_parameters.m

- The configuration of the simulation parameters can be performed through LTE_load_parameters.m. Where you can adjust parameters like bandwidth, channel estimation technique, channel model..

CRC_calculation.m

- CRC is calculated by using 3gpp defined polynomials.

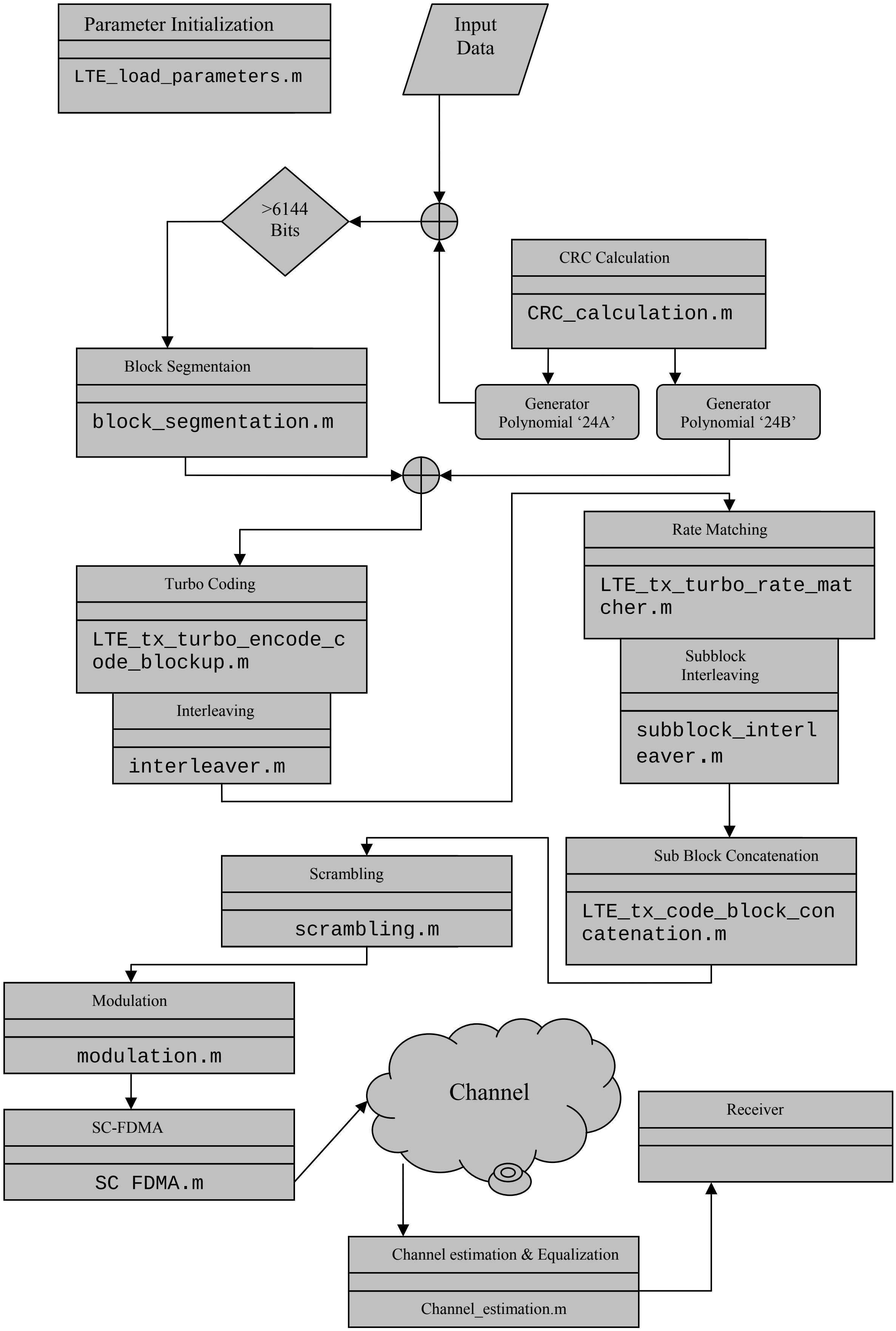

Figure 6.1 Implementation

block_segmentation.m

- Segmentation of transport block in small segments.

LTE_tx_turbo_encode_code_blockup.m (interleaver.m)

- Interleaving the segments for second input of encoder and applying channel coding.

LTE_tx_turbo_rate_matcher.m (subblock_interleaver.m)

- Rate matching the interleaved coded bits according to the recourses allocated to the users.

LTE_tx_code_block_concatenation.m

- Concatenation of segmented blocks.

scrambling.m

- Scramble the selected bits for transmition.

modulation.m

- Modulation of scrambled bits.

SC_FDMA.m

- Applying SC-FDMA multiple access technique.

Receiver

- Doing all steps in opposite at the receiver side too and performing channel estimation and equalization to get the channel estimation curves for LS and LMMSE. Also BER Vs SNR curves for different modulation schemes. One missing part in simulator is HARQ, because of time constraint.

Simulation Results 7

From simulation results I have concluded that LMMSE channel estimation algorithm gives good channel estimation performance compare to classical LS channel estimator. But on the other hand the computational complexity required by the LMMSE channel estimator is more, comparable to that of the LS channel estimator. I have simulated SISO single input single output LTE uplink channel with channel models described in section 5.3. The bandwidth is 5 MHz for the simulation, using all 300 sub carriers. A normal cyclic prefix of length is inserted among data to cancel the effect of multipath channel to remove ISI. In simulating the SISO system, only one port of an antenna is considered and this antenna port is treated as physical antenna. There are 300 sub carriers in one symbol for data and reference signal.

The modulation mapper employed according to the 3GPP specification which is QPSK. At the receiver side LS and MMSE channel estimation and frequency domain equalization is performed. The performance of the system is measured by measuring the bit error rate (BER). The designed simulator is flexible to use, there is option to use bandwidth from 1.4 to 20 MHz. Other simulation parameters described are summarized in following table 7.1.

Parameter	Assumption
Bandwidth	5 MHz
Channel Model	PedA,PedB,VehA,VehB
Data Modulation	QPSK
Data Channel	Localized FDMA
Antenna Configuration	SISO
Pilot	Zadoff-Chu
Channel Estimation	LS,LMMSE
Carrier Spacing	9.765 kHz
Number of subcarriers	300

Sample rate [MHz]	7.68
Carrier Frequency	2.1e9

Table 7.1 Simulation Parameters

Figure 7.1 to 7.4 shows the plots between SNR and MSE using LS estimation and LMMSE estimation respectively for different channel models. As it is clear from plots, increasing the channel taps degrades the estimation performance. In figure 7.1 red curve for LMMSE has better performance compare to black for LS channel estimation.

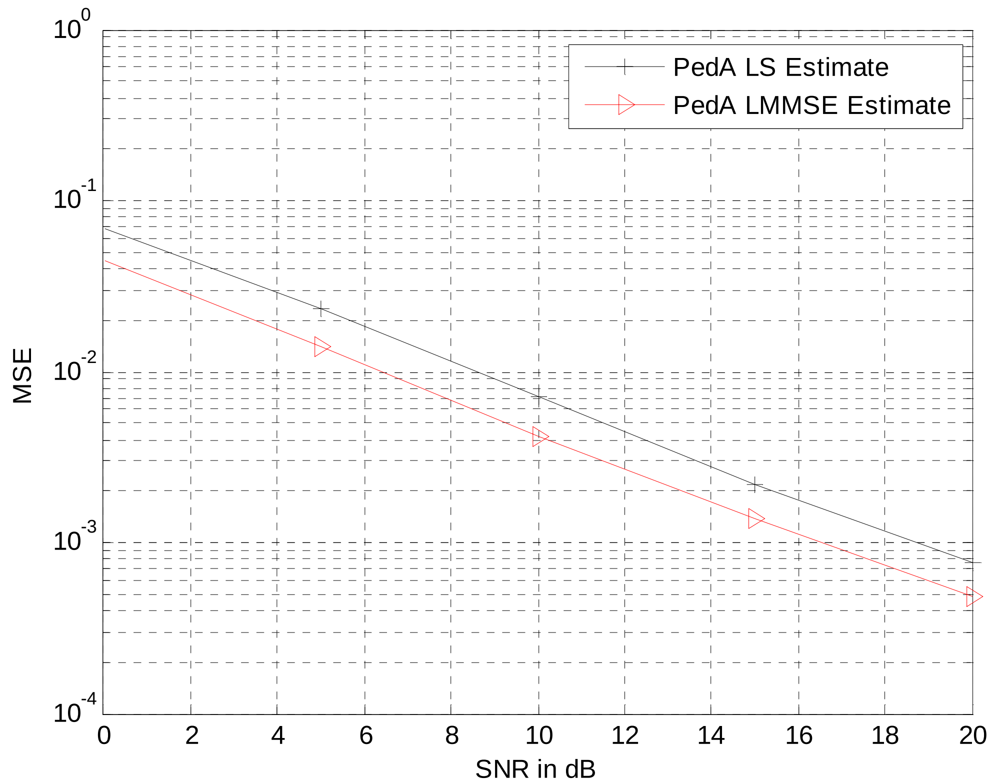

Figure 7.1 MSE vs SNR for LS & LMMSE Channel Estimation with PedestrianA Channel Model

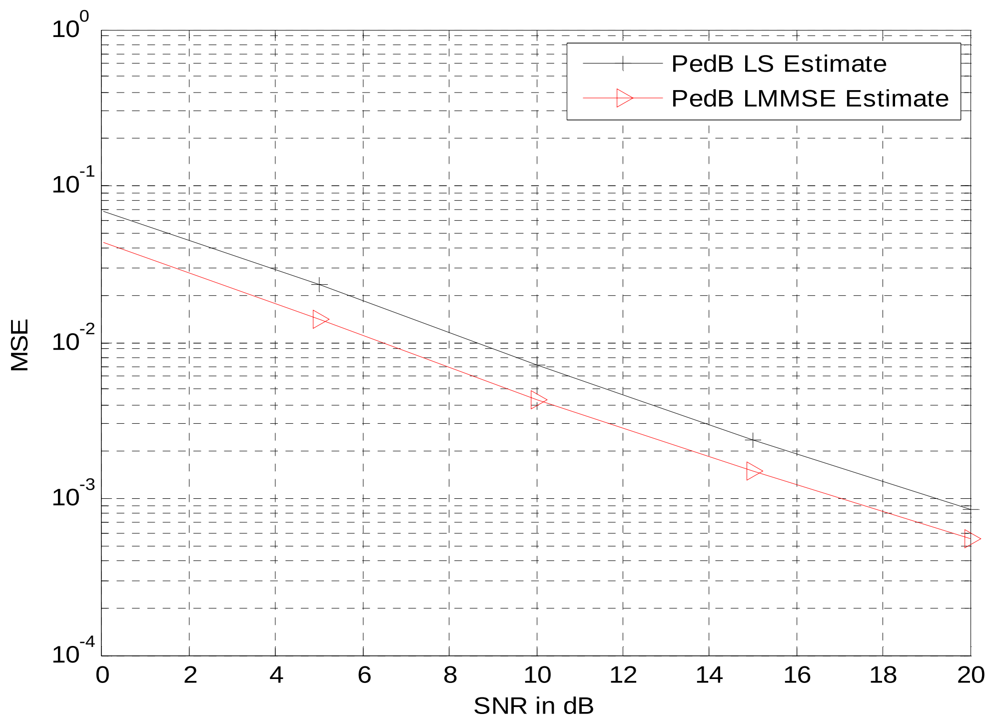

Figure 7.2 MSE vs SNR for LS & LMMSE Channel Estimation with PedestrianB Channel Model

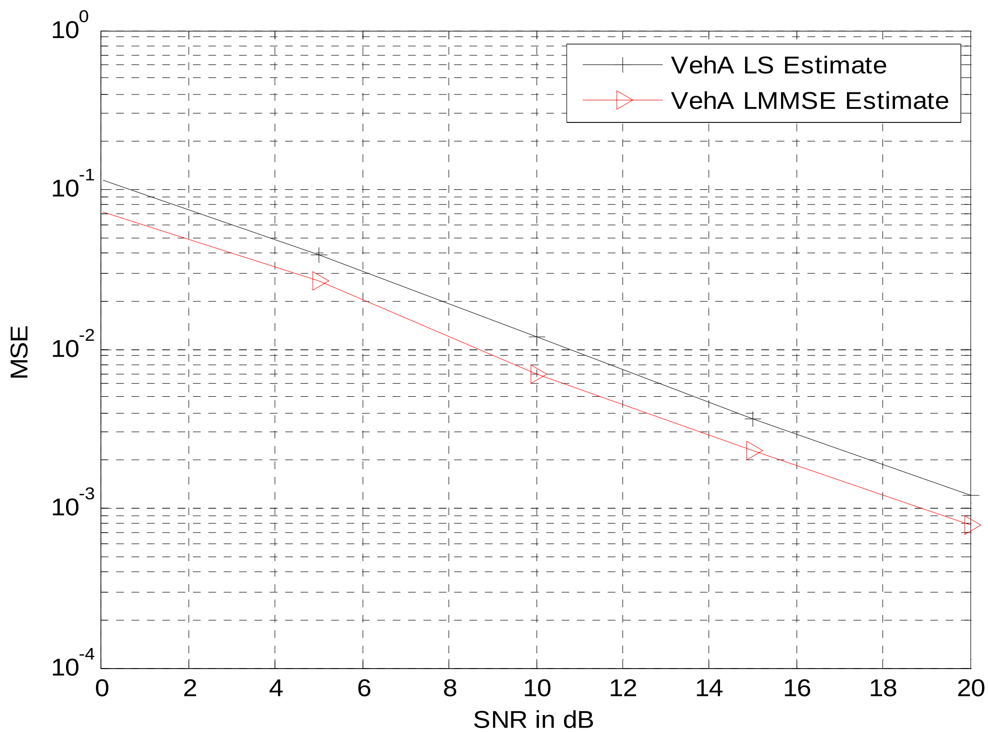

Figure 7.3 MSE vs SNR for LS & LMMSE Channel Estimation with VehicularA Channel Model

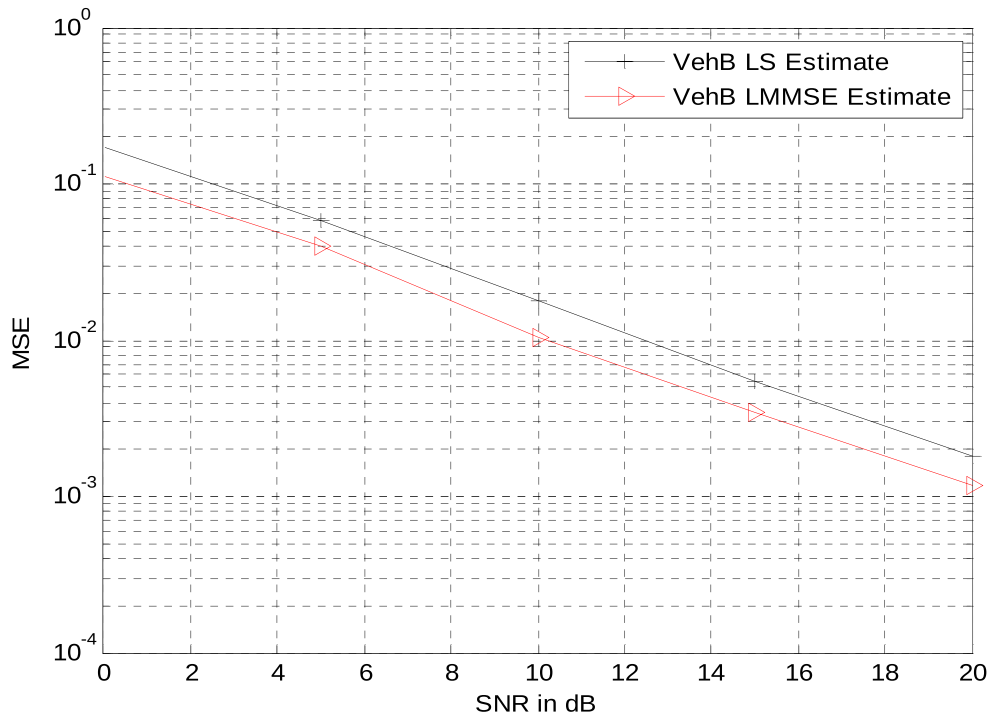

Figure 7.4 MSE vs SNR for LS & LMMSE Channel Estimation with VehicularB Channel Model

The performance of LTE uplink transceiver is shown in following figures in term of curves representing BER against SNR values and is compared with different channel models. Figures 7.5 to 7.8 illustrate BER versus SNR for QPSK. It is seen that by increasing the channel taps for the system performance degrades. Following simulation results compares LMMSE and LS estimation technique for different channel models.

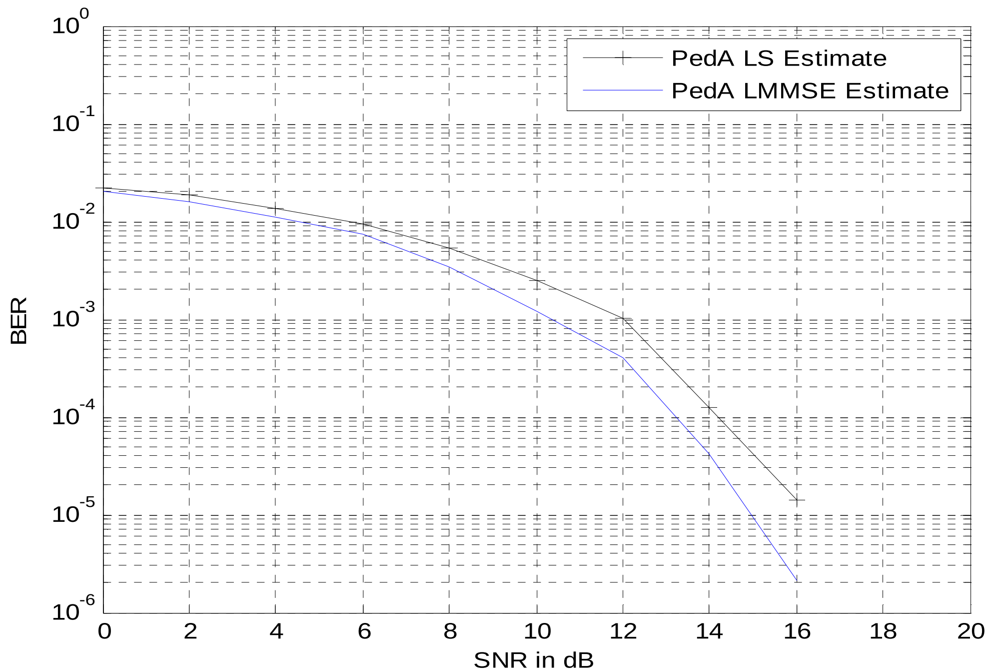

Figure 7.5 BER vs SNR for PedA using QPSK modulation with LMMSE & LS.

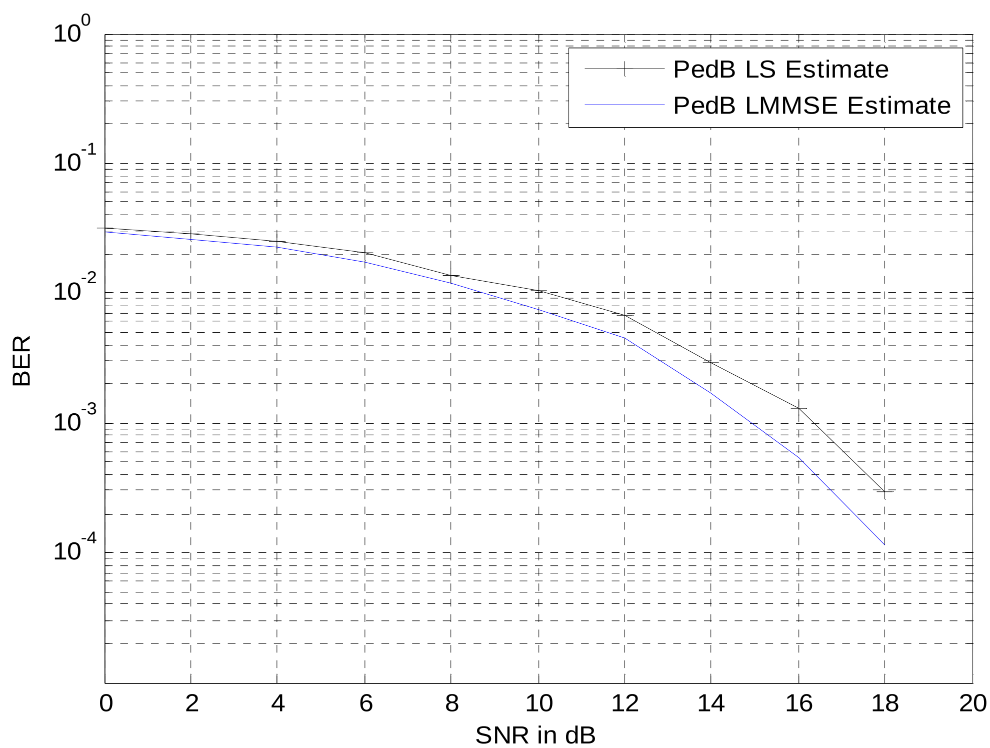

Figure 7.6 BER vs SNR for PedB using QPSK modulation with LMMSE & LS.

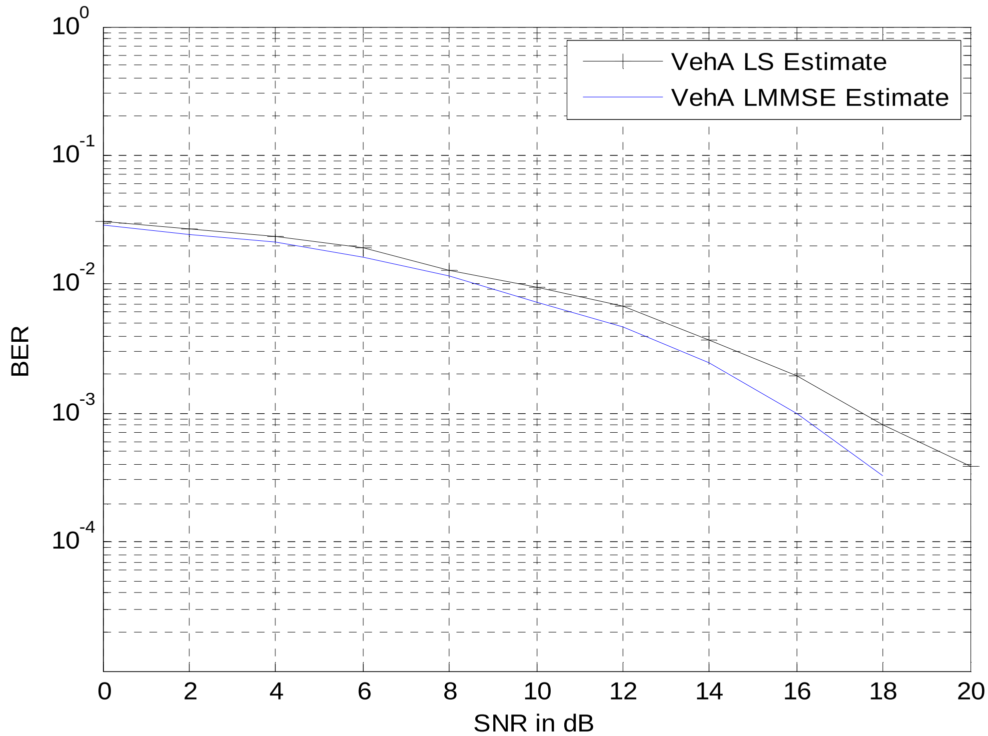

Figure 7.7 BER vs SNR for VehA using QPSK modulation with LMMSE & LS.

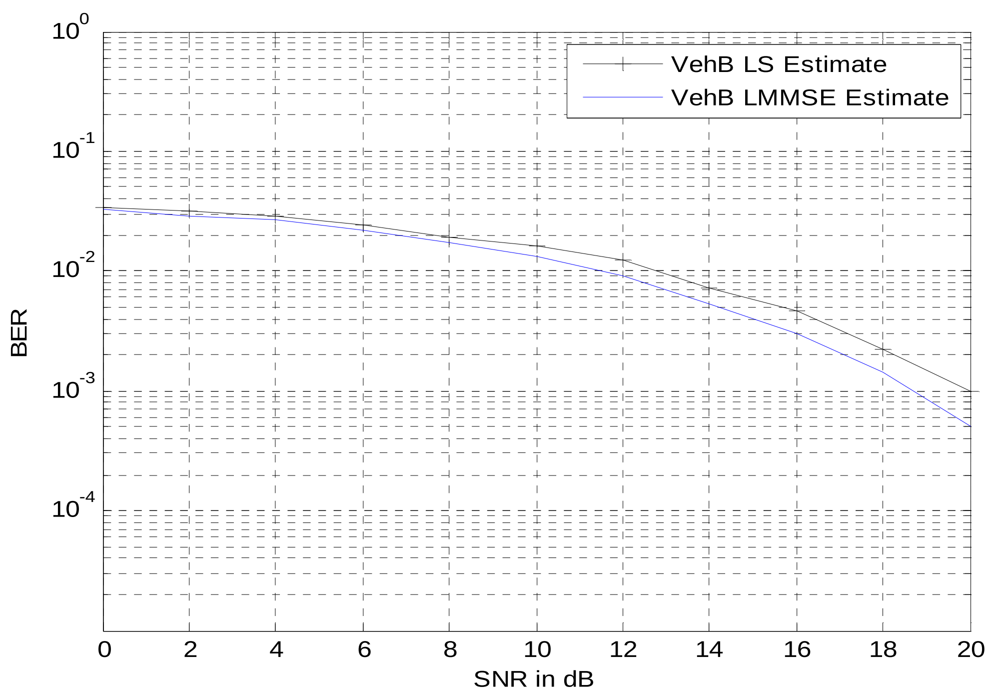

Figure 7.8 BER vs SNR for VehB using QPSK modulation with LMMSE & LS.

Conclusions and Future Work 8

The thesis investigated the uplink signal generation from UE for LTE. The parameters that were used are described in the 3GPP specification TS36.211 and 36.211.The work can be summarized as following:

Study of the physical layer of LTE which includes LTE uplink frame structure, transport layer structure and reference symbols structure.

- Using the 3GPP specifications a communication scenario is built for LTE uplink in MATLAB with SC-FDMA transmitter and receiver.
- Transmitted signal has to cater the phenomenon of multipath fading in wireless communication, Chapter 5 describes the details of channel models.
- The second part was to estimate these channel models using LS and LMMSE methods. For estimating the channel, pilot symbols are needed which is generated according to 3GPP specification.
- Estimation error was showed in simulation chapter from these plots it is clearly visible that LMMSE has less error compare to LS estimate.

In chapter 7 results have been presented by mean of simulations. The performance is measured in terms of BER Vs SNR and MSE Vs SNR. The thesis implemented only UL-SCH and PUSCH, the possible continuation of this thesis is to add the remaining channels in uplink which includes logical channels and physical control channel.

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