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“A Long Term Evolution (LTE) Downlink (DL) inspired channel simulator using the SUI 3 channel model”

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Dedicated to my uncle and aunty

Abstract

LTE (Long Term Evolution) is the last step towards the 4th generation of radio technologies designed to increase the capacity and speed of cellular networks. Where at present current generation of cellular technology dominated by 3G (third generation), LTE is marked as 4G. The third generation partnership project (3GPP) currently work for developing the 3rd generation mobile and telecommunication system with a future 4th generation system. This thesis mainly focuses on design of a LTE DL (downlink) inspired channel simulator using the SUI 3 channel model, here OFDM uses as a multiple access scheme. The performance of SUI 3 channel at LTE DL is measured by comparing the AWGN limit.

Acknowledgement

I would like to thank my supervisor Dr. Jörgen Nordberg for his guidance, suggestion and help during the development of this thesis. I feel proudly to have been inspired by his extraordinary encouragement, motivation, great intuition and hard work. Many thanks go to my friends who gave me valuable suggestions which greatly improve the quality of my thesis.

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30th August, 2009, karlskrona

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Acronyms

ADC	Analog to Digital Converter.
ARIB	Association of Radio Industries and business.
COST	Committee on Science and Technology.
DAC	Digital to Analog Converter.
EDGE	Enhanced Data rates for GSM Environment.
FFT	Fast Fourier Transform.
GSM	Global System for mobile communication.
GPRS	General packet radio service.
GRP	Gain Reduction Factor.
HSPA	High Speed Packet Access.
HSUPA	High Speed Uplink Packet Access.
HSPDA	High speed Downlink Packet Access.
HARQ	Hybrid Automatic Repeat Request.
ISI	Inter-symbol Interference.
IFFT	Inverse Fast Fourier Transform.
LTE	Long Term Evolution.
LOS	Line of Sight.
MIMO	Multiple Input Multiple Output.
MRC	Maximal Ratio Combination.
OFDM	Orthogonal Frequency Division Multiplexing.
OPEX	Operational Expenditure.
PRB	Physical Resource Block.

PCCC	Parallel Concatenated convolution Code.
QAM	Quadrature Amplitude modulation.
RMS	Root Mean Square.
SUI	Stanford University Interium.
SISO	Single Input Single Output.
SIMO	Single Input Multiple Output.
SC-FDMA	Single Carrier Frequency Division Multiplexing Access.
SON	Self Optimizing Network.
TTC	The Telecommunication Technology Committee.
TDD	Time Division Duplexing.
UE	User Equipment.
UMTS	Universal Mobile Telecommunication System.
WCDMA	Wide band Code Division Multiple Access.
XCVR	Transceiver.

Chapter 1

Introduction

1.1 Background

Mobile communications have experienced dramatic advances over the last two decades. The technologies are rapidly moving toward the convergence of the communications, computing and consumer's platforms and bridged the services across fixed and wireless networks.

Mobile broadband is becoming a reality, as the internet generation grows accustomed to having broadband access wherever they go, and not just at home or in the office. Out of the estimated 1.8 billion people who will have broadband by 2012, some two-thirds will be mobile broadband consumers and the majority of these will be served by HSPA (High Speed Packet Access) and LTE (Long Term Evolution) [1].

LTE is a jointly collaborated project with 3GPP. The main motto of this project is to improve the Universal Mobile Telecommunications System (UMTS).The main reason behind the name LTE is that the scientists are trying to establish a mobile broad band highway that will be support the future demand of mobile users like efficiency improvement, service enhancement, lowering cost and better integration with other standard. In December 1998, Third Generation partnership project established. The members of 3GPP project are ARIB/TTC (Japan), China communication standard association, Telecommunications industry association (North America) and telecommunication technology associate (South Korea). Figure 1.1 describes the 3GPP group technical specifications.

Release	Date	Specification
Release 9	December ,2008 to December ,2009 in progress	Approve the functional freeze of LTE.
Release 8	3rd June ,2008	Long Term Evaluation
Release7	December,2007	HSPA
Release 6	December,2004-March,2005	WLAN,HSUPA and MBMS
Release 5	March,2002-June,2002	HSPDA , IMS
Release 4	March,2001	Feature included all IP-core network
Release 99	March,2000	First UMTS 3G networks

Table 1.1: Technical specifications published by the 3GPP group.

1.2 LTE upgrade path

LTE represents a major advance in cellular technology and it defines a new high speed radio access method for high speed data and media transport as well as high capacity voice support well into the next decade. Actually LTE provides an evolution route for UMTS network operators towards fourth generation (4G) mobile networks with today's 2G and 3G networks. It offers a richer, more compelling mobile service environment by embracing GSM (Global System for Mobile Communication), GPRS (General Packet Radio Service) and EDGE (Enhanced Data rates for GSM Environment) as well as WCDMA (Wide Band Code Division Multiple Access) and now HSPA. This is shown in Figure 1.1.

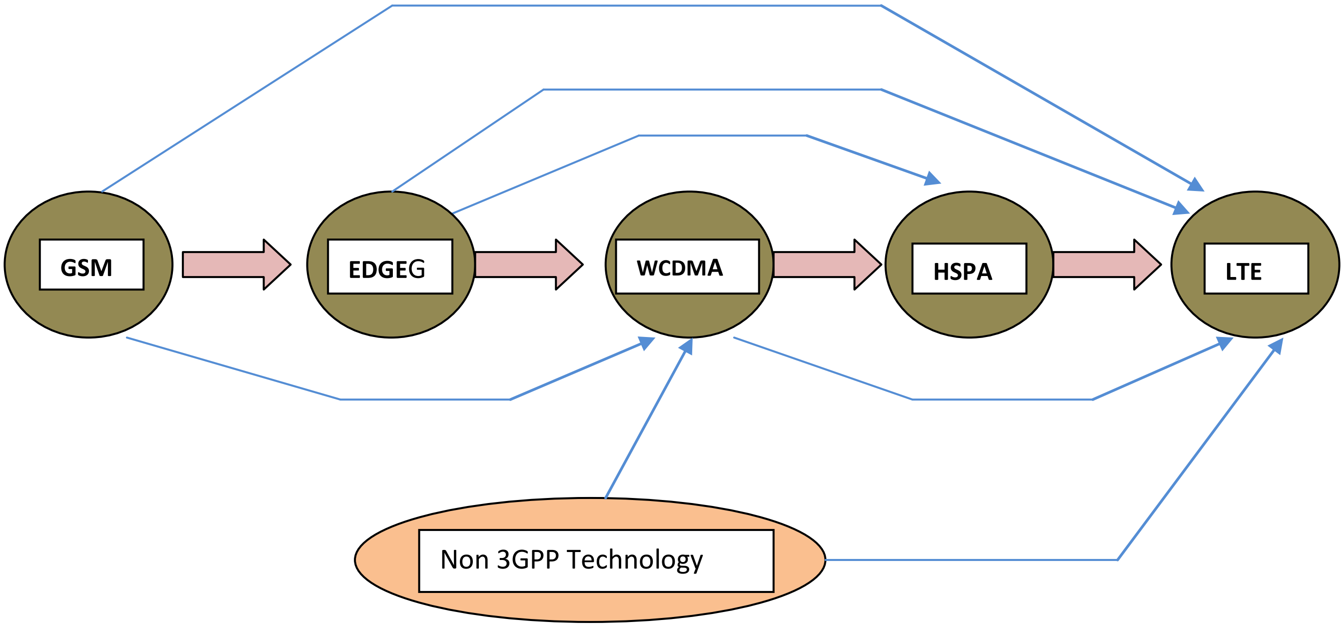


Figure 1.1: LTE upgrade path.

1.3 LTE key features

The key features of LTE are described below:

1. Enhanced air interface allows increased data rates: LTE provides greater improvement in overall performance and efficiency through the use of OFDM technology for the interface rather than WCDMA based UTRAN (UMTS terrestrial radio access network) and HSPA system.
2. High Spectral Efficiency: LTE provides greater spectral efficiency and it gives the opportunity to mobile operators to increase number of customers within existing and future spectrum allocation with a reduce cost of delivery.
3. Reduced Latency: LTE reduces round trip times to 10 ms or less, which makes LTE to provide interactive, real time services.
4. An all- IP environment: The most significant feature of LTE is its transition to a ‘flat’, all- IP based core network with a simplified architecture and open interfaces.
5. Flexible Radio planning: LTE can deliver optimum performance in a cell size of up to 5 km. It is capable of the delivery effective performance in cell size of up to 30 km radius but with more limited performance available in cell sizes up to 100 km radius.
6. Co-existence with legacy standards and systems: LTE supports smooth seamless service handover and users of LTE can access basic data services even when they are in areas without LTE coverage.
7. Extra cost reduction capabilities: One of the key features of LTE is multi vendor RAN (MVR) or self optimizing networks (SON) which reduces OPEX (Operational expenditure) and provides lower costs per bit [2].

1.4 3G LTE Evolutions

The comparison among WCDMA (UMTS), HSPA, HSDPA/HSUPA, HSPA+ and LTE are described in the following Table1.2 [1].

	WCDMA (UMTS)	HSPA, HSDPA/HSUPA	HSPA+	LTE
Max downlink speed	384 k	14 M	28M	100M
Max uplink speed	128 k	5.7 M	11M	50 M
Latency round trip time(approx)	150 ms	100 ms	50 ms(max)	10ms
3GPP release	Rel. 99/4	Rel. 5/6	Rel. 7	Rel. 8
Approx years of initial roll out	2003/4	2005/6 HSDPA 2007/8 HSUPA	2008/9	2009/10
Access technology	CDMA	CDMA	CDMA	OFDMA/SC-FDMA

Table 1.2: 3G LTE Evolution.

1.5 LTE time schedules

It is anticipated that the first LTE networks and terminal devices will be launched commercially by the end of 2010 as 3GPP Release 8 is now being consolidated. LTE will replace WCDMA and HSPA gradually and dominate the world's mobile infrastructure markets after 2011, shown in the Figure 1.2.

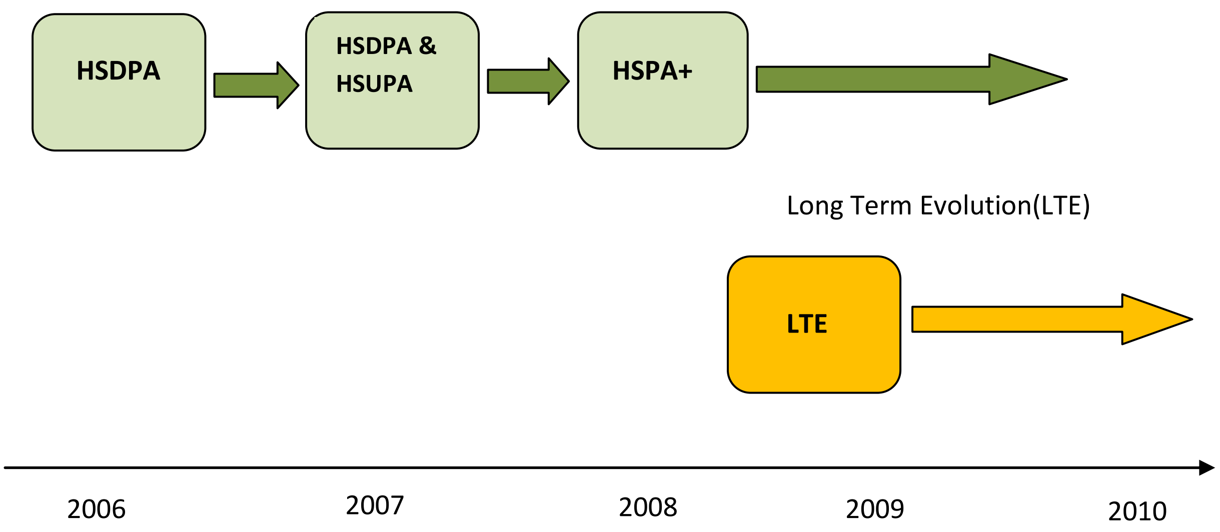


Figure1.2: Evolution timeframe for planned 3GPP systems.

1.6 Thesis Motivation

LTE is the next step in mobile communication and will be introduced in 3GPP Release 8. LTE uses Orthogonal Frequency Division Multiplexing (OFDM) as its radio access technology together with advanced antenna technology.

The main focus of this thesis is to build a simplified LTE Downlink simulator using the SUI 3 Channel model in BPSK and QPSK modulation scheme. This simulator has been carried out by means computer based simulation using MATLAB. This simulator generate theoretical and practical BER Vs SNR curve. By using this simulator all the SUI model and M-QAM modulation scheme could be implemented in future work according to 3GPP channel model.

1.7 Outlines of the thesis

The structure of this thesis is organized as follows. Chapter one presents introduction and key features of LTE system. Chapter two presents details overview of OFDM and the physical layer structure of LTE system. The details description of OFDM based UMTS-LTE transceiver system design is depicted in chapter 3. The simulation result of a simplified LTE Downlink using the SUI 3 channel model in BPSK and QPSK modulation scheme is mainly focus of chapter four. Finally, chapter five represents conclusion of this thesis and some suggestion for extending the work in the future.

Chapter 2

Physical layer of LTE System

The 3GPP LTE depicts a major advanced in mobile technology. LTE is designed not only to provide substantial performance improvements but also to vastly reduce the cost per bit, enabling operators to embrace new business models. LTE encompasses high speed data, multimedia unicast and multimedia broadcast services.

The LTE PHY is important for conveying both data and control information between an enhanced base station (eNodeB) and mobile user equipment (UE).

The LTE physical layer uses OFDMA in DL and single carrier-frequency division multiple access (SC-FDMA) on the uplink (UL). OFDMA distribute sub-carrier among several users within specific symbol period. Further, LTE support also MIMO for higher data rates and fight against multi path fading [3].

The LTE describe both frequency division FDD and time TDD to separate UL and DL traffic. This thesis will focus on the DL for LTE FDD System.

In Figure 2.1, the physical layer block diagram of LTE system is depicted. At first input bit stream converted serial to parallel then it go to the 1/3 turbo encoder. Adaptive modulation scheme maps the encoded bit to complex valued QAM symbols and T/F mapper puts this QAM symbol on the corresponding subcarrier l in OFDM symbols k.

Then again convert the symbol time domain and appended cyclic prefix. Thus we get transmitted column vector $S_{k,I}=[S_{1kI}\ \ S_{2k,I}\ldots\ldots S_{Mk,I}]^{T}$. Then all the signals are received by the received antenna and after converting the signal in frequency domain with cyclic prefix removal finally it receive by the MIMO receiver. If the acknowledgement is not match then the transmitter sent the signal again.

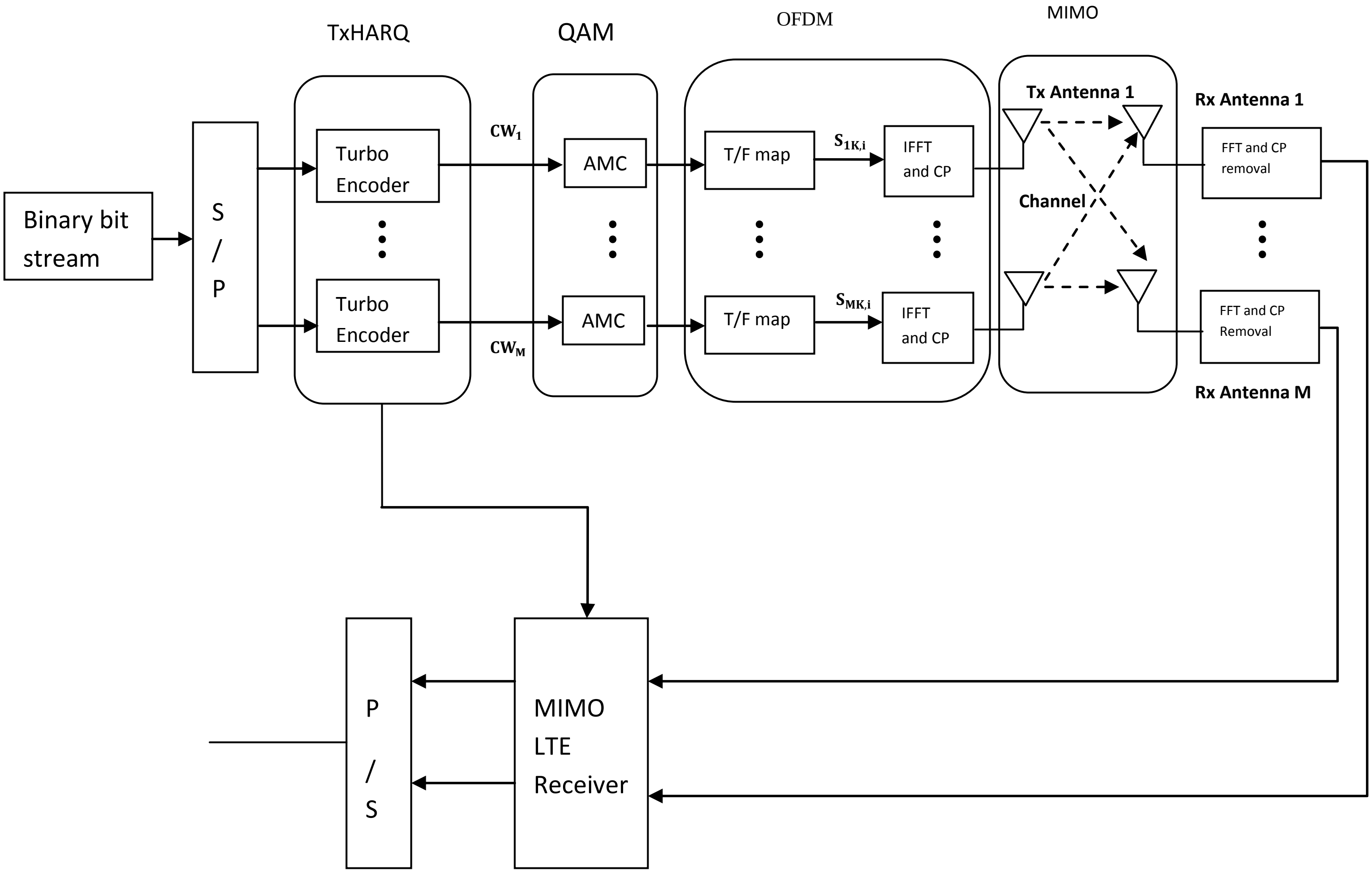


Figure 2.1: 3GPP LTE physical layer implementation.

2.1 Channel coding

Channel coding is a method to reduce information rate and increase the relability of channel by adding redundancy to the information symbol vector resulting in a longer coded vector of symbols that are distinguishable at the output of the channel this goal is achieved.

2.1.1 Turbo coding

In 1993, Berrou el al. presented turbo codes. This code perform better than other encoder at very low signal to noise ratio. Turbo code performance is very close to shanon limit error correction. A BER of 10^{-5} is reported for a SNR of 0.7 dB [20]. Turbo code is a forward error correction (FEC) scheme. Concatenation of two convolutional code makes turbo codes. Turbo code can be concatenated in series, parallel or in hybrid manner. This concatenated code can be introduce as parallel concatenated convolution codes (PCCC), serial concatenated convolution codes (SCCC). Same information bits operate on two encoders in PCCC. One encoder encode the output of other encoder in SCCC. The hybrid concatenation consists of the combination of PCCC and SCCC. 3GPP recommend to use 8 state turbo code. The 8 state turbo code perform better than 4 state turbo code.

2.2 OFDM

OFDM is a method of digital modulation in which a signal is divided into several narrow band channels at different frequencies. Modulation and multiplexing both are combined in OFDM. OFDM was introduced in 1950 but it was only completed in 1960's. It was used in parallel data transmission and frequency division multiplexing. In the 1960's the OFDM technique was used in several high-frequency military system. Earlier OFDM was not popular because the sinusoidal generator and coherence demodulator. It was too expensive and complex. In 1966, Chang [6] patented the structure of OFDM and publish the concept of using orthogonal over lapping multi-tone signals for data communication. In 1971, Weinstein and Ebert [7] first introduce the DFT to parallel data transmission system which become part of modulation and demodulation process. In the 1990's OFDM was exploited for wide band data communications. Now-a-days advances in VLSI technology allow implementation of fast and cheap FFT and IFFT operation introduce OFDM popularity in different applications.

In OFDM the subcarrier pulse used for transmission is chosen to be rectangular. This has the advantage that the task of pulse forming and modulation can be performed by a simple Inverse Discrete Fourier Transform (IDFT) which can be implemented very efficiently as a Inverse Fast Fourier Transform (IFFT). Accordingly in the receiver only need a FFT to reverse this operation.

In OFDM, the spectrums of the subcarriers are not separated but overlap. By using an IFFT for modulation implicitly chose the spacing of the subcarriers in such a way that at the frequency where evaluate the received signal, all other signals are zero. In order for this orthogonality to be preserved the following must be true:

The receiver and the transmitter must be perfectly synchronized. This means they both must assume exactly the same modulation frequency and the same time-scale for transmission which usually is not the case. The analog components, part of transmitter and receiver, must be of very high quality [3].

In order to combat the effects of multipath propagation OFDM symbols are artificially prolonged by periodically repeating the 'tail' of the symbol and precede the symbol with it. At the receiver this so called guard interval is removed again. As long as the length of this interval Δ is longer than the maximum channel delay all T_{max} reflections of previous symbols are removed and the orthogonality is preserved. Of course this is not for free, since by preceding the useful part of length T_u by the guard interval we lose some parts of the signal that cannot be used for transmitting information. Taking all this into account the signal model for the OFDM transmission over a multipath channel becomes very simple.

$$\mathbf{z}_{I,k} = \mathbf{a}_{I,k} * \mathbf{H}_{I,k} + \boldsymbol{n} \quad \text{...(2.1)}$$

The transmitted symbols at time-slot $\boldsymbol{I}$ and subcarrier $\boldsymbol{k}$ are only disturbed by a factor $\mathbf{H}_{I,k}$ which is the (the Fourier transform of the cir) at the subcarrier frequency and by additional white Gaussian noise $\boldsymbol{n}$

As far as the analog components are concerned experience has shown that in the broadcasting applications under consideration here, they are not so critical. What remains is to establish 'perfect' synchronization. This requires a very sophisticated receiver [3].

2.2.1 OFDM transmission has several advantages over a single-carrier system

With its parallel transmission, an OFDM symbol time is longer than the symbol time of a serial system. This prolongation of the symbol time means that the multipath delay corresponds to a smaller portion of the total symbol time, Hence OFDM is less sensitive to multipath—it can tolerate longer multipath delays, and it reduces the need or the complexity of equalizers in the receiver. The longer the OFDM symbol, the better the tolerance against multipath fading, but the symbol time T_s has to be much smaller than the channel coherence time T_ *C*oherence. If T_s is of the same magnitude as T_ coherence, the channel will change considerably during the symbol time, and it will need complex equalizers despite using OFDM. The fact that OFDM is robust against multipath can also be described in the frequency domain: the longer the symbol time, the narrower the sub channel and the narrower the sub channel, the closer it is to a frequency-flat channel [4].

In an OFDM system, frequency-selective fading will affect only a small percentage of the sub carriers. Performance on these sub carriers will be severely degraded, but since only a small percentage is affected, the bits on these sub carriers can be recovered effectively with channel coding.

OFDM gives access to the frequency domain for scheduling and adaptation since each sub carrier can be independently scheduled and independently adapted to the radio conditions on each sub carrier. For example, users can be multiplexed freely over the sub carriers to give users their best-quality sub carriers and one sub carrier can use 4QAM and a code rate of 1/4 while another sub carrier can use 64QAM and a code rate of 1.

In OFDM the intra-cell interference can be avoided because of CDMA type of multi user detection. It reduces the complexity of receiver and only FFT processor is required.

OFDM’s provision of flat sub channels is particularly valuable to systems using multiple input and multiple output (MIMO) since most MIMO theory assumes flat channels. Although OFDM has several strong advantages, it naturally also has drawbacks.

2.2.2 Drawbacks

Generally cyclic prefix inserts in OFDM to minimize the loss of efficiency. For closely spaced subcarriers, symbols in OFDM should be high. Due to the closeness of sub carriers, they lose their orthogonality due to the frequency errors. As a result various problems occur which degrades the system performance. First phase noise occurs in the received signal which introduces ISI in the sub carriers. Second doppler shift effect can cause a devastating to the OFDM. Third any type of frequency error will cause interference between sub carrier symbols.

The amplitude of an OFDM signal has a Gaussian-like distribution with a large dynamic range. This implies a high PAPR (Peak-to-Average Power Ratio), which in turn means that the amplifiers in the system will be less efficient and that the DAC and the ADC will be more complex (and expensive) since they need to operate with good precision over a large range.

In receiver side, tight synchronization between users is required for FFT. So, pilot signals are used for synchronizations.

2.2.3 Overview of OFDM based structure

The OFDM modulation technique based on frequency division multiplexing technique (FDM). The main difference between OFDM and traditional FDM technique is that OFDM modulation technique having sub carrier and the entire sub carrier orthogonal to each other. This kind of modulation technique is used in OFDM system to overcome the effect of frequency selective channel. The frequency selective channel happen when the transmitted signal gets in multi-path environment, because of multi-path environment a given signal is corrupted or overlapped by previous signal. This condition is called inter-symbol interference (ISI). To avoid this ISI , the symbol duration must be longer then the delay that caused by multi-path channel. So every symbol is prolonged copy of its tacit that called cyclic prefix (CP). Also the spectral efficiency of OFDM is better than FDM because in OFDM the sub-carrier are overlapped but they are orthogonal to each other. According to the 3 GPP releases for frequency spacing between sub-carrier is either 15 KHz or 7.5 KHz. The difference between OFDM and OFDMA is OFDMA allows multiple users to share available bandwidth. Each user is assigned specific time frequency resource that is called recourse girder block (RB). The basic principle of EVTRA to share the data channel with many user, for every transmission time interval (TTI) 1 ms [7] [9].

In LTE system the scheduling decision is dynamically performs for each subtracts so the member of resource block allocated dynamically depending on the channel condition quantity.

2.2.4 Mapping of Sub-carrier

Figure 2.2 illustrates the mapping between sub-carrier with the frequency spectrum. The occupied sub-carrier is accumulated around the frequency 0. So, half accumulated sub-carrier is placed in the positive side and half of accumulated sub-carrier is placed in the negative side. It denoted the accumulated sub-carrier at positive side is { N_n+1 ……. N_{BW}} and the accumulated sub-carrier of negative side is {1……N_n} to keep the utilize bandwidth less than the specific bandwidth, the unused carrier are placed at the top of the spectrum. As a result, it reduces the requirement of analog filter in receiver and transmitter side [9].

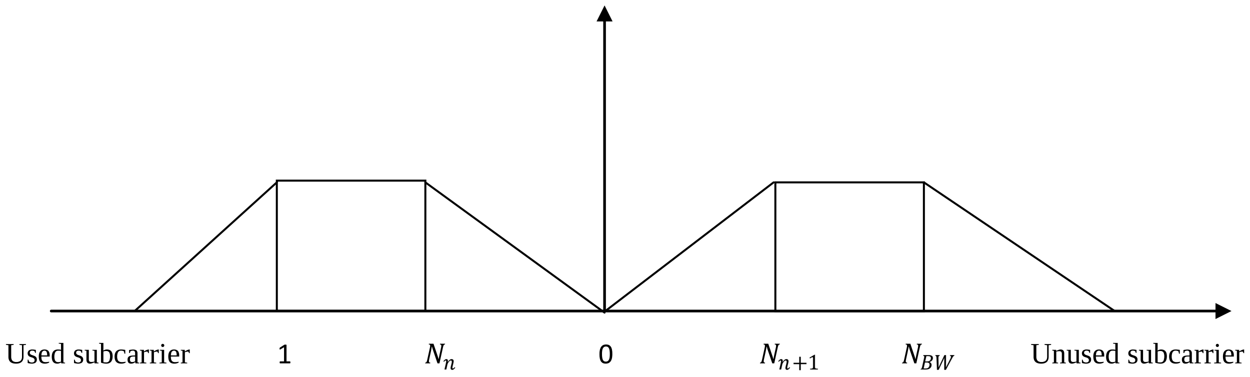


Figure 2.2: Place the half of the sub-carrier at negative side and other half of the sub-carrier at positive side.

2.3 MIMO and MRC

In order to increase link robustness and data rate for the LTE downlink, The LTE PHY can optionally use multiple transceivers (XCVR) both base station and UE. When signal strength are low and multipath condition are challenging then maximal ratio combination (MRC) is used to enhance link reliability in challenging propagation condition. MIMO is used to increase system data rates[6].

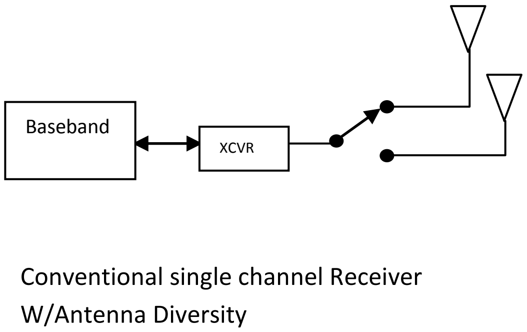


Figure 2.3: Single channel receiver.

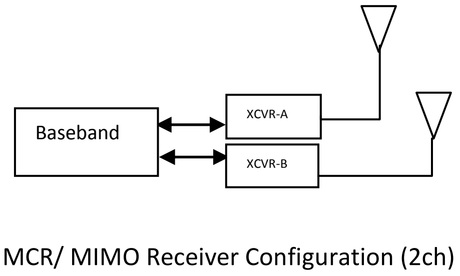


Figure2.4: Receiver structure for MRC/MIMO**.**

Figure 2.3 represents a single channel receiver with antenna diversity. Multiple antennas are deployed in receiver structure but it could not support MRC/MIMO. In Figure 2.4, the basic receiver structure for both MRC and MIMO are sometimes it refers as a multiple antenna technology.

With MRC, two or more separate antenna transceiver pair receives the signal. The antenna is physically separate, and therefore they have distinct channel impulse response. The compensation of channel is applied to each received signal within the baseband processor before being linearly combined to create a single composite received signal.

When combined by this way receive signals add coherently with the base band processor. The thermal noise for every transmitter is uncorrelated. So the linear combination of the channel compensated signals at the base band processor results in an increase in SNR of 3 dB on average for a two-channel MRC receiver in a noise limited environment [6].

The improvement of SNR condition because of combining, MCR receivers are robust in the presence of frequency selective fading. MRC enhance link reliability but it does not increase data rate. In MRC mode data is sent by a single antenna but processed at the receiver via two or more receiver.

MIMO on the other hand increase data rates. The task is done by using multiple antennas on both the transmitter and receiver end.

In order to successfully receive MIMO transmission, from each transmitting antenna receiver must determine the channel impulse response. By sequentially transmitting known reference signal from each transmitting antenna, LTE channel impulse response is determine. In Figure 2.5, MIMO operation requires a prior knowledge of all channel response [11].

In order to successfully receive a MIMO transmission, the receiver must determine the channel impulse response from each transmitting antenna. In LTE, channel impulse responses are determined by sequentially transmitting known reference signals from each transmitting antenna as shown in Figure 2.5

R_1				X			R_1				X		
X				R_1			X				R_1		
R_1				X			R_1				X		
											R_1		
X				R_1			X						

Antenna 0

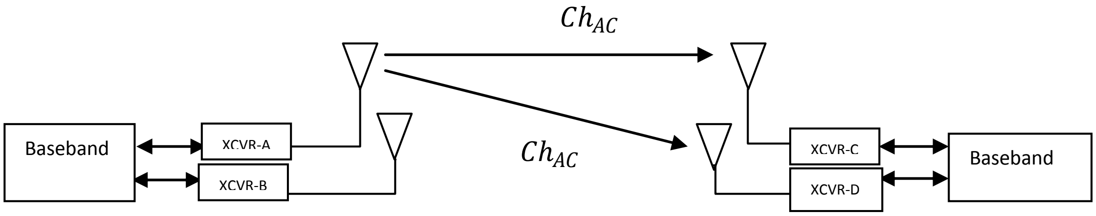
X	**Denotes Unused Resource element**
R_1	**Reference signal from Antenna 1**
R_0	**Reference signal from Antenna 0**

X				R_0			X				R_0		
R_0				X			R_0				X		
X				R_0			X				R_0		
R_0				X			R_0				X		

Antenna 1

Figure 2.5: Reference signals transmitted sequentially to compute channel responses for MIMO operation.

In Figure 2.5, describes the reference signal transmission process. Here R0 denote the reference signal from transmission antenna 0 and R1 denote the reference signal from transmission antenna A1. If there are two transmission antennas when one transmission antenna transmits the signal then other antenna is idle. By observing the resource grid of antenna 0 it seen that every sixth element of the column is transmit the reference signal but in other side in antenna 1 it seen that every sixth grid of the column is unused resource element.



$$S_C = REF_A * Ch_{AC}$$

$$S_D = REF_A * Ch_{AC}$$

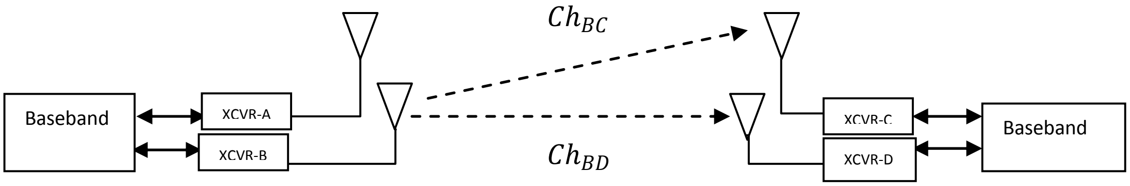
Figure 2.6: Reference signal transmitted from antenna A

Figure 2.6 shows two transmission antennas, A and B, and two receiving antennas, C and D. When antenna A transmit signal, antenna B is idle. So signal from antenna is transmitted through the channel Ch_{AC} .The receive signal in antenna C is $S_C=REF_A* Ch_{AC}$ and receive signal in antenna D is

$S_D=REF_A* Ch_{AC}$.

Figure 2.7 shows two transmission antennas, A and B, and two receiving antennas, C and D. When antenna A transmit signal, antenna B is idle . So signal from antenna is transmitted through the channel Ch_{AC}. The receive signal in antenna C is S_C=REF_A* Ch_{AC} and receive signal in antenna D is

S_D=REF_A* Ch_{AC}.

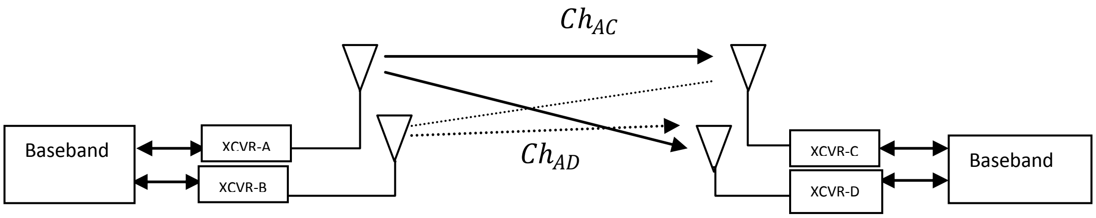


$$S_C = REF_B * Ch_{BC}$$

$$S_D = REF_B * Ch_{BD}$$

Figure2.7: Reference signal transmitted from antenna B

Figure 2.8 shows two transmission antennas, A and B, and two receiving antennas, C and D. When antenna B transmit signal antenna A is idle. So signal from antenna is transmitted through the channel Ch_{AC} and channel Ch_{BD}. The receive signal in antenna C is S_C=REF_B* Ch_{BC} and receive signal in antenna D is S_D=REF_B* Ch_{BD}.



$$S_C = [DATA_A * Ch_{AC}] + [DATA_B * Ch_{BC}]$$

$$S_D = [DATA_A * Ch_{AD}] + [DATA_B * Ch_{BD}]$$

Fig-2.8: Data transmitted simultaneously from BOTH antennas

When two transmission antennas A and B both transmit signal simultaneously then each receiving antenna C and D receive signal from both transmission antenna so the total signal of each receiving antenna is the addition of the signal of both transmission antenna. Figure2.8 shows 2x2 MIMO systems.

There is a total three channel impulse response. When one transmitter antenna sends the reference signal, then other antenna is idle. When the channel impulse response is known, the data will be transmitted through both antennas simultaneously [11].

2.4 Typical channel model

The 3GPP group and technical specification group radio access networks define typical channel model for mobile networks in technical report [12], according to the technical report the typical channel are

- Channel model for urban area (TU_x).
- Channel model for rural area (RA_x).
- Channel model for Hilly Terrain area (HT_x).

3GPP also defines defaults speed for that models, the speed of typical channel model are depicted on the Table 2.1

Name of the channel model	The speed of mobile
TU_x	3 km/hr
	50 km/hr
	120 km/hr
RA_x	120 km/hr
	250 km/hr
HT_x	120 km/hr

Table 2.1: Default mobile speed for typical channel model. (According to 3GPP TR 25.943 v5)

3GPP define statistical model for typical channels. The statistical model for three typical channels is depicted in Table 2.2-2.4.

Tap No.	Relative time(μs)	Avg. relative power	Doppler spectrum
1	0	-5.7	Class
2	0.217	-7.6	Class
3	0.512	-10.1	Class
4	0.514	-10.2	Class
5	0.517	-10.2	Class
6	0.674	-11.5	Class
7	0.882	-13.4	Class
8	1.230	-16.3	Class
9	1.287	-17.1	Class
10	1.311	-17.4	Class
11	1.349	-19.0	Class
12	1.533	-19.0	Class
13	1.535	-19.8	Class
14	1.622	-21.5	Class
15	1.818	-21.6	Class

16	1.836	-22.1	Class
17	1.884	-22.6	class
18	1.943	-23.5	Class
19	2.048	-24.3	Class
20	2.140	-24.5	Class

Table 2.2: channel model for urban area. (According to 3GPP TR 25.943 v5)

Tap no	Relative time(μs)	Avg. Relative power	Doppler spectrum
1	0	-5.2	Direct path, w_s=0.7 w_d
2	0.042	-6.4	Class
3	0.101	-8.4	Class
4	0.129	-9.3	Class
5	0.149	-10.0	Class
6	0.245	-13.1	Class
7	0.312	-15.3	Class
8	0.410	-18.5	Class
9	0.469	-20.4	Class
10	0.528	-22.4	Class

Table 2.3: Channel model for rural area (According to 3GPP TR 25.943 v5)

Tap No.	Relative time	Avg. relative power	Doppler spectrum
1	0	-3.6	Class
2	0.356	-8.9	Class
3	0.441	-10.2	Class
4	0.528	-11.5	Class
5	0.546	-11.8	Class
6	0.609	-12.9	Class
7	0.625	-13.0	Class
8	0.842	-16.2	Class
9	0.916	-17.3	Class
10	0.941	-17.7	Class
11	15.00	-17.6	Class
12	16.172	-22.7	Class
13	16.492	-24.1	Class
14	16.876	-25.8	Class
15	16.882	-26.2	Class

16	16.978	-29.0	Class
17	17.615	-29.9	Class
18	17.827	-30.0	Class
19	17.849	-30.7	Class
20	18.016	-30.9	Class

Table 2.4: Channel model for hilly terrain area (According to 3rd Generation partnership project)

Chapter 3

System model

In this chapter the system models that have been used in the LTE simulator will be presented. The used system model is outlined in Figure 3.1

In transmitter side the digital random data set is generated uniformly. These blocks of digital data set have been paralleled and mapped into complex data blocks using M-QAM modulation technique. Every complex data block referred to a symbol of data is attached to an individual sub-carrier. The Inverse Fast Fourier Transform (IFFT) is used in order to generate the time version of transmitted signal. The time domain signals corresponding to all subcarriers are orthogonal to each other. However, the frequency spectrum overlaps. To remove ISI on the transmitted signal inserted cyclic prefix in front of every transmitted symbol in the block diagram.

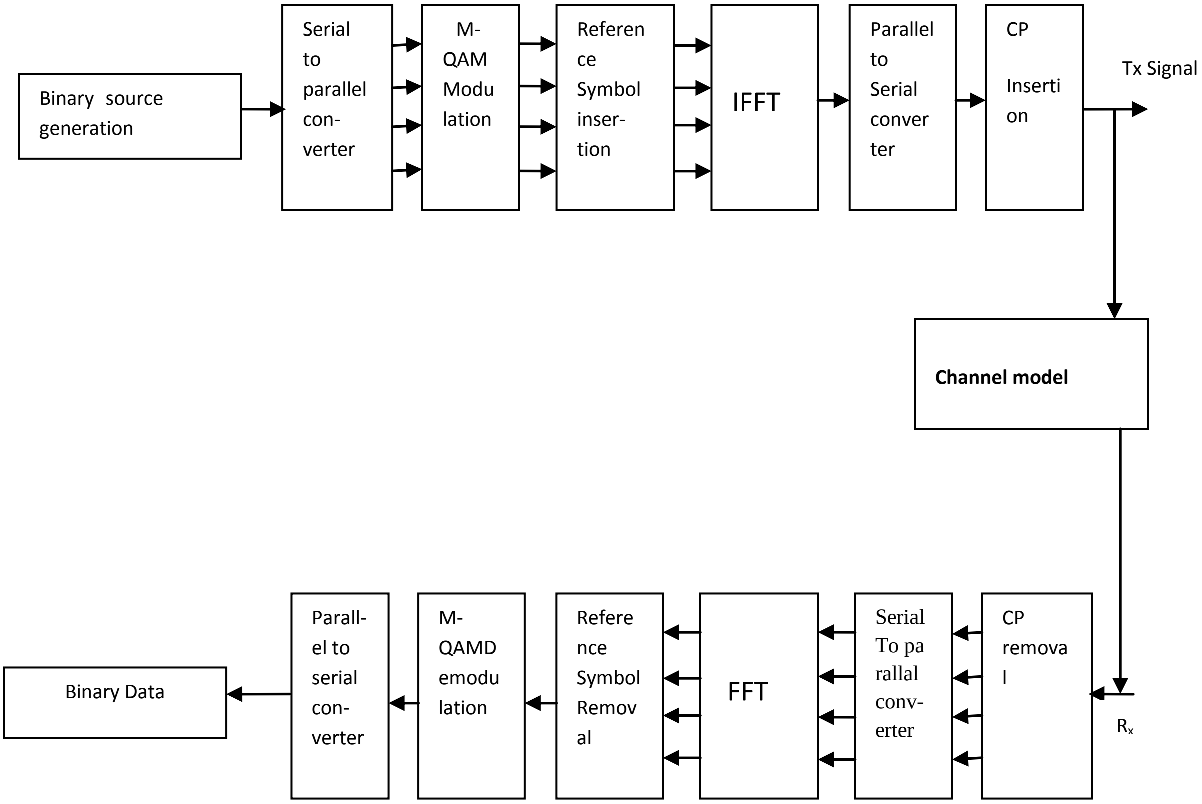


Figure 3.1: Block diagram of LTE transmitter and receiver.

3.1 Channel model

In a mobile communication when a transmitter and receiver transmit and receive data and signal it uses channel. So, channel model is a crucial issue in all communication. A channel model is a set of rules or ways from which data or signal will smoothly sent or receive through the channel. A good channel model is essential for a high class of communication. A nice channel model could save bandwidth, signal power that increases the system capability.

3.1.2 AWGN channel model

The additive white Gaussian channel model is the one of the simplest channel model in wireless communication. It is very simple because a white noise is only added with the wireless channel. In additive white noise a specific and equal amount of noise is added in every frequency spectrum. The AWGN channel model does not consider any fading effect, Inter-symbol interference that's why it is very simple and straight forward. It is a simple mathematical model it only consider the thermal noise and short noise.

3.1.3 The COST 259 channel model

COST 259 (European Cooperation in Science and Technology) is the EU research forum. All European University, manufacturers and operators are participant in this forum. COST 259 is the successor of COST 207. One of the main aims of COST 259 is overcome the limitation of GSM channel model. UMTS also target of this model with emphasis on adaptive antenna and directional channel.

One of the main key differences between COST259 channel model and previously designed model is that, in COST 259 channel model all the real world complex condition is consider while channel distribution rather than few 'typical' condition [13].

Environment and distance are two main parameter of occurrence of different channel in the case of probability density. COST259 channel environment identification is given in table 3.1 [12].

There are similarities between the microcontroller environments and GSM models.

Macro-cell	Micro-cell	Pico-cell
Typical urban	(street canyons)	Corridor or tunnels
Bad urban	Open places	Factory
Village area	Tunnels	Residential house
Hilly terrain	Street	Lounge

Table 3.1: COST 259 preliminary environment identification (According to 3rd generation partnership project)

In model work of COST 259, a number of properties of the propagation channel have been considered. The properties are given in table 3.1.

COST 259 model considered propagation properties.

i) Path loss.

ii) Shadowing.

iii) Time dispersion.

iv) Fast fading.

v) Polarization.

vi) Angular dispersion.

vii) Multiple clusters.

viii) Dynamic channel variations.

The shape of channel is given by one or several clusters. here every cluster is exponentially decreasing with delay and laplacian in azimuth.

A number of Ray-Leigh fading path make each cluster, plus a LOS (Line of Sight) path to get a Rice fading.

3.1.4 Modified Stanford university interim (SUI) channel model

Channel model represent a predefined scenario according to specific requirement of a system as it is impossible to virtually simulate a real scenario. This SUI channel model is to account for 30 degree directional antenna. The parameters were selected based upon statistical model parameter [19].

The SUI model could be summarized according to the following tables

Terrain types	SUI channels
C	SUI-1,SUI-2
B	SUI-3,SUI-4
A	SUI-5,SUI-6

Table 3.2: Terrain types related to SUI channel.

Doppler	Low delay spread	Moderate delay spread	High delay spread
Low	SUI-3		SUI-5
High		SUI-4	SUI-6

Table 3.3: The SUI channel condition when K factor low.

Doppler	Low delay spread	Moderate delay spread	High delay spread
	SUI-1,2		

Table 3.4: The SUI channel condition when k factor high

The general structure of SUI channel model

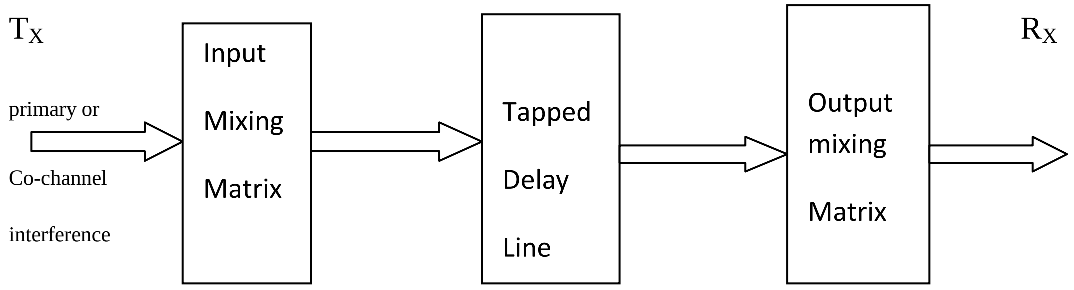


Figure 3.2: SUI model structure.

The above mentioned structure is for MIMO channels and also supports other configuration like single input single output (SISO) and single input multiple outputs (SIMO). The SUI channel structure is the same for the primary and interfering signal [19].

Input Mixing Matrix

This part of the model use for model correlation between all the input signal if multiple antenna uses in transmission side.

Input Mixing Matrix: This part models correlation between input signals if multiple transmitting antennas are used.

Tapped Delay Line Matrix

This part models is uses for the multipath fading of the channel. The multipath fading is modeled as a tapped-delay line with 3 taps with non-uniform delays. The gain associated with each tap is characterized by a distribution (Rician with a K-factor > 0, or Rayleigh with K-factor = 0) and the maximum doppler frequency.

Output Mixing Matrix

This part models the correlation between output signals if multiple receiving antennas are use in the receiver side. Using the above general structure of the SUI channel and assuming the following scenario, six SUI channels are

Scenario for modified SUI channels

- Cell size: 7 km.
- BTS antenna height: 30 m.
- Receive antenna height: 6 m.
- BTS antenna beam width: 120^o
- Receive Antenna Beam width: omnidirectional (360^0) and 30^0.

For a 30^0 antenna beam width, 2.3 times smaller RMS delay spread is used when compared to an omnidirectional antenna RMS delay spread. the 2nd tap power is attenuated additional 6 dB and the 3rd tap power is attenuated additional 12 dB (effect of antenna pattern, delays remain the same). For the omnidirectional receive antenna case, the tap delays and powers are consistent with the COST 207 delay profile models

- Vertical Polarization only
- 90% cell coverage with 99.9% reliability at each location covered.

Considering the above scenario, the six specified channel model are as under

<table>
<tr><th></th><th>Tap1</th><th>Tap2</th><th>Tap3</th><th>Units</th></tr>
<tr><td>Delay</td><td>0</td><td>0.4</td><td>0.9</td><td>µs</td></tr>
<tr><td>Power (omni ant.)</td><td>0</td><td>-15</td><td>-20</td><td>dB</td></tr>
<tr><td>90% K-fact.(omni)</td><td>4</td><td>0</td><td>0</td><td></td></tr>
<tr><td>75%K-fact.(omni)</td><td>20</td><td>0</td><td>0</td><td></td></tr>
<tr><td>Power (30_o ant.)</td><td>0</td><td>-21</td><td>-32</td><td>dB</td></tr>
<tr><td>90% K-fact. (30_o)</td><td>16</td><td>0</td><td>0</td><td></td></tr>
<tr><td>75% K-fact. (30_o)</td><td>72</td><td>0</td><td>0</td><td></td></tr>
<tr><td>Doppler</td><td>0.4</td><td>0.3</td><td>0.5</td><td>Hz</td></tr>
<tr><td colspan="3">Antenna Correlation: ρENV = 0.7
Gain Reduction Factor: GRF = 0 dB
Normalization Factor: Fomni = -0.1771 dB
F30° = -0.0371 dB</td><td colspan="2">Terrain Type: C
Omni antenna: τ_{RMS} = 0.111 µs,
overall K: K = 3.3 (90%); K = 10.4 (75%)
30° antenna: τ_{RMS} = 0.042 µs,
overall K: K = 14.0 (90%); K = 44.2 (75%)</td></tr>
</table>

Table 3.5: SUI-1 channel model

<table>
<tr><th></th><th>Tap1</th><th>Tap2</th><th>Tap3</th><th>Units</th></tr>
<tr><td>Delay</td><td>0</td><td>0.4</td><td>1.1</td><td>µs</td></tr>
<tr><td>Power (omni ant.)</td><td>0</td><td>-12</td><td>-15</td><td>dB</td></tr>
<tr><td>90% K-fact.(omni)</td><td>2</td><td>0</td><td>0</td><td></td></tr>
<tr><td>75%K-fact.(omni)</td><td>11</td><td>0</td><td>0</td><td></td></tr>
<tr><td>Power (30_o ant.)</td><td>0</td><td>-18</td><td>-27</td><td>dB</td></tr>
<tr><td>90% K-fact. (30_o)</td><td>8</td><td>0</td><td>0</td><td></td></tr>
<tr><td>75% K-fact. (30_o)</td><td>36</td><td>0</td><td>0</td><td></td></tr>
<tr><td>Doppler</td><td>0.2</td><td>0.15</td><td>0.25</td><td>Hz</td></tr>
<tr><td colspan="3">Antenna Correlation: ρ_{ENV} = 0.5
Gain Reduction Factor: GRF = 2 dB
Normalization Factor: F_{omni} = -0.3930 dB
$F_{30°}$ = -0.768 dB</td><td colspan="2">Terrain Type: C
Omni antenna: τ_{RMS} = 0.202 µs,
overall K: K = 1.6 (90%); K = 5.1 (75%)
30° antenna: τ_{RMS} = 0.069 µs,
overall K: K = 6.9 (90%); K = 21.8 (75%)</td></tr>
</table>

Table 3.6: SUI-2 channel model

<table>
<tr><td></td><td>Tap1</td><td>Tap2</td><td>Tap3</td><td>Units</td></tr>
<tr><td>Delay</td><td>0</td><td>0.4</td><td>0.9</td><td>µs</td></tr>
<tr><td>Power (omni ant.)
90% K-fact.(omni)
75%K-fact.(omni)</td><td>0
1
7</td><td>-5
0
0</td><td>-10
0
0</td><td>dB</td></tr>
<tr><td>Power (30_o ant.)
90% K-fact. (30_o)
75% K-fact. (30_o)</td><td>0
3
19</td><td>-11
0
0</td><td>-22
0
0</td><td>dB</td></tr>
<tr><td>Doppler</td><td>0.4</td><td>0.3</td><td>0.5</td><td>Hz</td></tr>
<tr><td colspan="2">Antenna Correlation: ρ_{ENV} = 0.4
Gain Reduction Factor: GRF = 3 dB
Normalization Factor: F_{omni} = -1.5113 dB
$F_{30°}$ = -0.3573 dB</td><td colspan="3">Terrain Type: B
Omni antenna: τ_{RMS} = 0.264 µs,
overall K: K = 0.5 (90%); K = 1.6 (75%)
30° antenna: τ_{RMS} = 0.123 µs,
overall K: K = 2.2 (90%); K = 7.2 (75%)</td></tr>
</table>

Table 3.7: SUI-3 channel model

<table>
<tr><td></td><td>Tap1</td><td>Tap2</td><td>Tap3</td><td>Units</td></tr>
<tr><td>Delay</td><td>0</td><td>1.4</td><td>4</td><td>µs</td></tr>
<tr><td>Power (omni ant.)
90% K-fact.(omni)
75%K-fact.(omni)</td><td>0
0
1</td><td>-4
0
0</td><td>-8
0
0</td><td>dB</td></tr>
<tr><td>Power (30_o ant.)
90% K-fact. (30_o)
75% K-fact. (30_o)</td><td>0
1
5</td><td>-10
0
0</td><td>-20
0
0</td><td>dB</td></tr>
<tr><td>Doppler</td><td>0.2</td><td>0.15</td><td>0.25</td><td>Hz</td></tr>
<tr><td colspan="2">Antenna Correlation: ρ_{ENV} = 0.3
Gain Reduction Factor: GRF = 4 dB
Normalization Factor: F_{omni} = -1.9218 dB
$F_{30°}$ = -0.4532 dB</td><td colspan="3">Terrain Type: B
Omni antenna: τ_{RMS} = 1.257 µs,
overall K: K = 0.2 (90%); K = 0.6 (75%)
30° antenna: τ_{RMS} = 0.563 µs,
overall K: K = 1.0 (90%); K = 3.2 (75%)</td></tr>
</table>

Table 3.8: SUI-4 channel model

	Tap1	Tap2	Tap3	Units
Delay	0	4	0.9	µs
Power (omni ant.)	0	-5	-10	dB
90% K-fact.(omni)	0	0	0	
75%K-fact.(omni)	0	0	0	
50% K-fact (omni)	2	0	0	
Power (30° ant.)	0	-11	-22	dB
90% K-fact. (30°)	0	0	0	
75% K-fact. (30°)	2	0	0	
50% K-fact. (30°)	7	0	0	
Doppler	2	1.5	2.5	Hz
Antenna Correlation: $\rho_{ENV} = 0.3$ **Gain Reduction Factor:** GRF = 4 dB **Normalization Factor:** $F_{omni} = -1.5113$ dB $F_{30°} = -0.3573$ dB		**Terrain Type:** A **Omni antenna:** $\tau_{RMS} = 2.864$ µs, overall K: K = 0.3 (90%); K = 0.1 (75%),K=1.0(50%) **30° antenna:** $\tau_{RMS} = 1.276$ µs, overall K: K = 2.2 (90%); K = 7.2 (75%) ;k=4.2(50%)		

Table 3.9: SUI-5 channel model

	Tap1	Tap2	Tap3	Units
Delay	0	14	20	µs
Power (omni ant.)	0	-10	-14	dB
90% K-fact.(omni)	0	0	0	
75%K-fact.(omni)	0	0	0	
50% K-fact (omni)	1	0	0	
Power (30o ant.)	0	-16	dB	
90% K-fact. (30°)	0	0		
75% K-fact. (30°)	2	0		
50% K-fact. (30°)	5	0		
Doppler	0.4	0.3	0.5	Hz
Antenna Correlation: $\rho_{ENV} = 0.3$ **Gain Reduction Factor:** GRF = 4 dB **Normalization Factor:** $F_{omni} = -.5613$ dB $F_{30°} = -0.1184$ dB		**Terrain Type:** A **Omni antenna:** $\tau_{RMS} = 5.240$ µs, overall K: K = 0.1 (90%); K = 0.3 (75%),K=1.0(50%) **30° antenna:** $\tau_{RMS} = 1.276$ µs, overall K: K = 0.4 (90%); K = 1.3 (75%) ;k=4.2(50%)		

Table 3.10: SUI-6 channel model

3.1.4 Implemented channel model

In this thesis the SUI 3 channel model have been implemented.

Chapter 4

Simulation Results

The simulation of the thesis are organized in two part in first part of the simulation theoretical and practical value verified, second part of the simulation Sui 3 models performance is investigated in respect to AWGN limit to BPSK and QPSK modulation.

The modulation techniques are

- BPSK
- QPSK

In respect to the modulation technique the following parameter are investigated

- Signal to noise ratio (SNR).
- Bit error rate (BER).

The tools are used during the simulation

- Microsoft windows vista home edition.
- Matlab 7.5.0(R2007b).
- Gaussian noise.
- Rician fading characteristic is considered in the SUI model.
- All plots are done in SNR Vs BER performance in respect to theoretical and practical value.

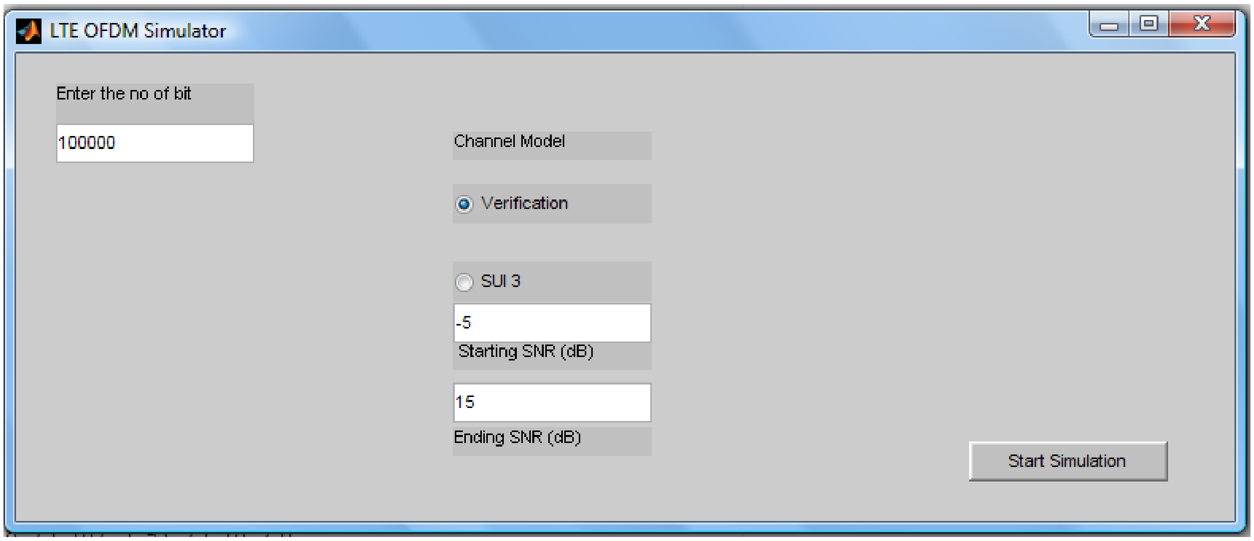
The modulation parameters are used to make the simulation more efficient.

The simulated results are divided into two cases:

1) Using the AWGN channel.
2) Using the SUI 3 channel.

4.1 AWGN Channel

In first part of the simulation, the theoretical and simulated BER are compared with respect to QPSK modulation technique when AWGN channel is being used.



Enter the no of bit: 100000

Channel Model
● Verification
○ SUI 3

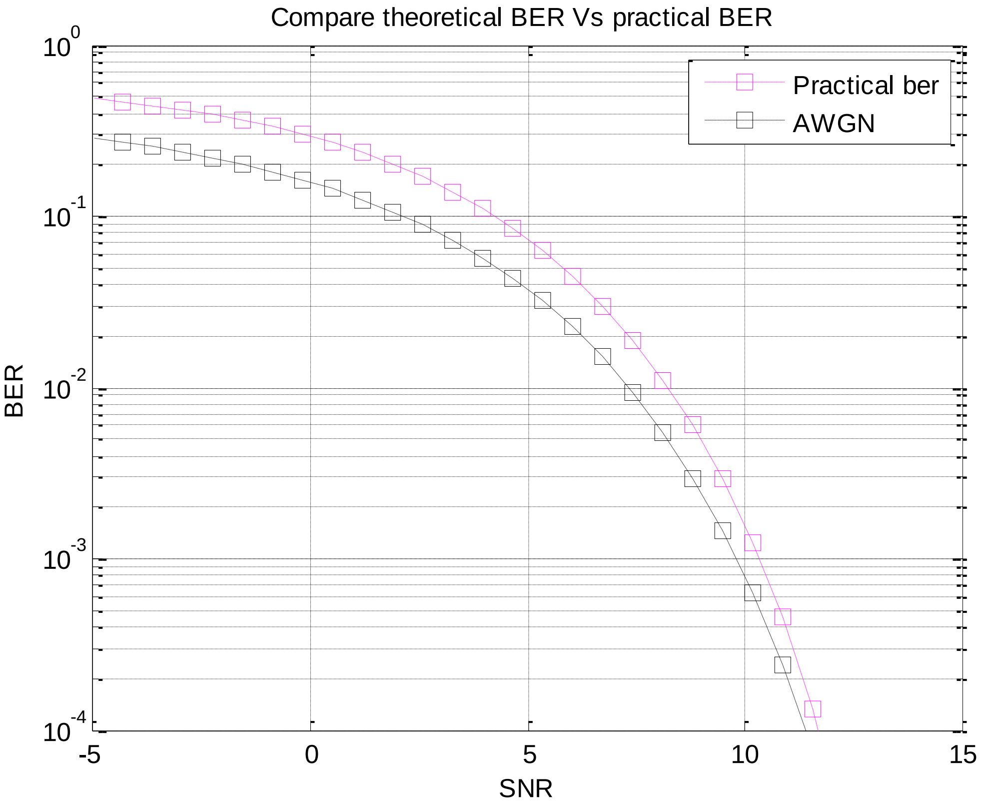
-5
Starting SNR (dB)

15
Ending SNR (dB)

Figure 4.1: Graphical interface of simulation part one.

The common parameter are depicted in Figure 4.1 on the graphical interface. In addition 64 OFDM subcarrier and 64 FFT are considered during the simulation.

The results are presented in Figures 4.1-4.2 and it can be see that the results from the simulator match the theoretical limit in QPSK modulation.



.

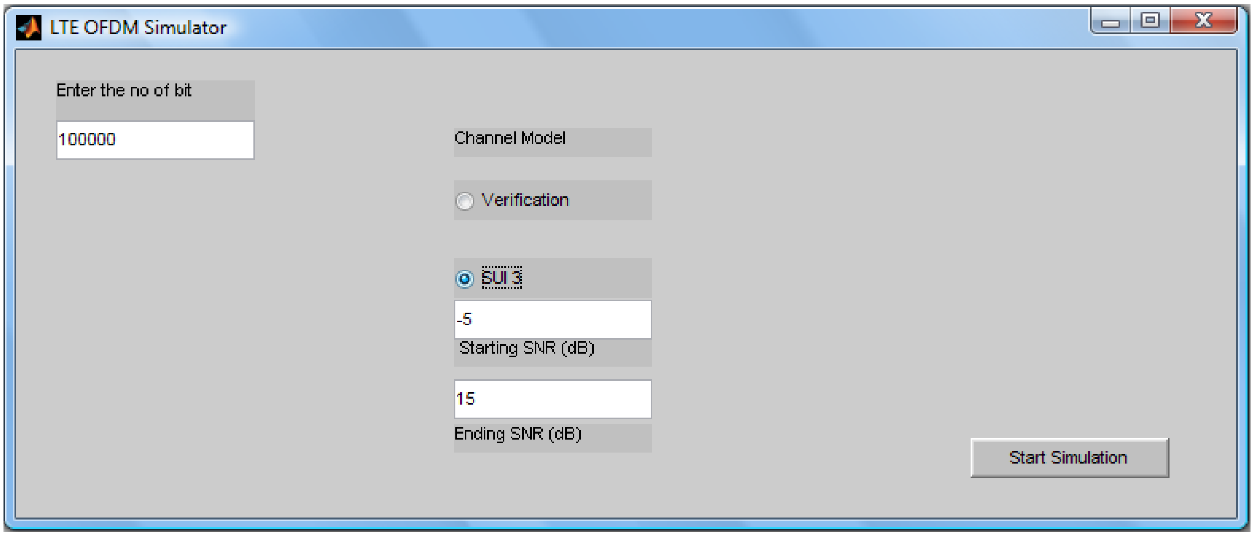
Figure 4.2: Theoretical and Simulated BER are compared in QPSK modulation.

4.2 Simulation results using the SUI3 channel

The following SUI 3 settings were used.

The simulation parameter consider in the third part of the simulation are

Observation parameter : 4Hz
No. of taps of the Doppler filter : 256
Doppler resolution of SUI parameter : 0.1(used in re sampling process)
Accuracy of re sampling : 20
Power in each tap in dB : [0 -5 -10]
Rician k-factor in linear scale : [1 0 0]
Tap delay in microsecond : [0.0 0.5 1.0]
Doppler maximal frequency parameter in Hz : [0.4 0.4 0.4]
Antenna Correlation (envelop correlation coefficient) : 0.4
Gain normalization factor : -1.5113



Enter the no of bit: 100000

Channel Model
○ Verification
● SUI 3

Starting SNR (dB): -5
Ending SNR (dB): 15

Figure 4.3:Graphical interface of simulation part Two.

The common parameter are depicted in Figure 4.3 on the graphical interface. In addition, 80 OFDM subcarrier and 128 FFT are considered during the simulation.

All simulated results are compared to the theoretical AWGN limit for QPSK modulation. The simulation plots is presented in Figures 4.3-4.4. Further are the SNR loss presented in table 4.1when using the SUI 3 model over the AWGN model for BER=0.01.

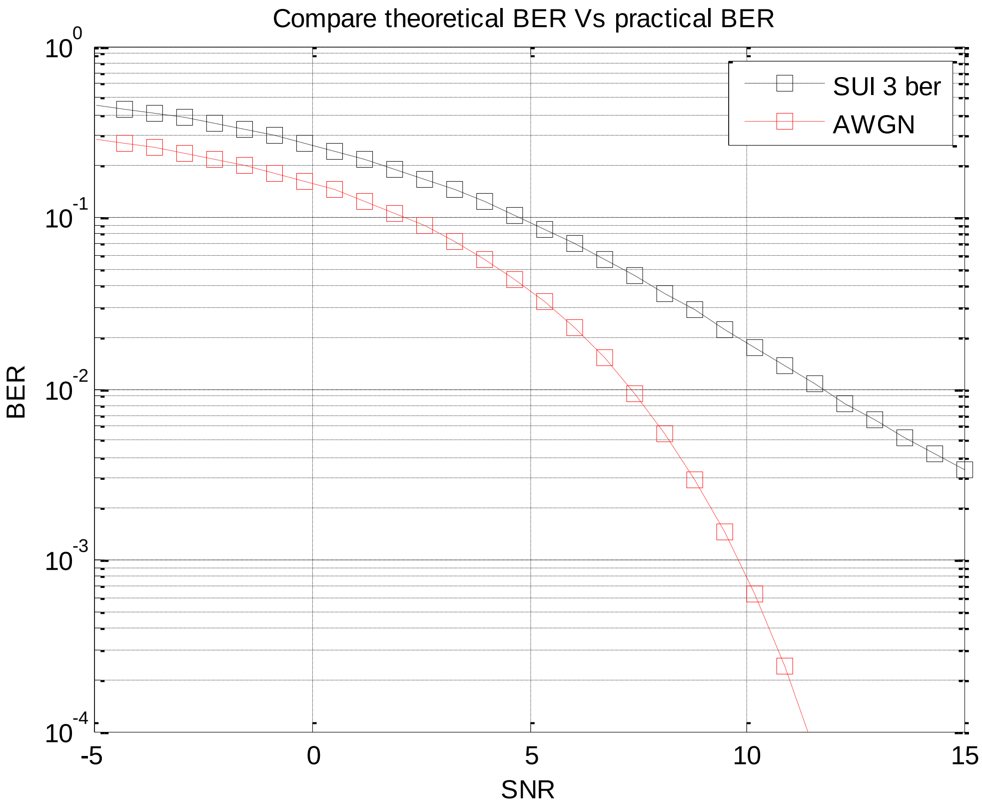


Figure 4.4: Compare the simulated results when using QPSK modulation together with the SUI 3 channel with the AWGN limit.

By observing the Figure 4.4 when BER=0.01.

Value	SNR	Bits/Symbol
Theoritical	7	2
Practical	11.5	2

Table 4.1: Comparison between theoretical and practical value in QPSK modulation in SUI 3 model when BER=0.01.

Chapter 5

Conclusion and future work

In this thesis work, a simplified LTE downlink system was simulated using the SUI 3 channel model. The simulator was verified by comparing the simulated BER with the AWGN limit for the given modulation scheme. It is clear from the simulation that for BER = 0.01 there is SNR loss of 4 dB when using the SUI3 channel compared to the AWGN theoretical limit. This was expected since no coding or channel equalizer was implemented.

Future work:

- Using this ground different channel model can be implemented according to the 3GPP channel model specification.
- In this thesis only SUI 3 model is implemented, using this background rest of the SUI model could be implemented.
- In this thesis only QPSK modulation technique is implemented, Other M-QAM modulation technique could be implemented.
- By using channel coding and equalizer in the receiver part the simulation performance could increase.
- To decrease the different between transmitted data and received data find a good solution.
- I do not consider coding in this thesis so that can be left for future work.

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