Chapter 4

Long Term Evolution-Advanced: Downlink Physical Layer

Long Term Evolution-Advanced: Downlink Physical Layer

4.1 Introduction

The International Telecommunications Union (ITU), the organization that sets the international standards for next-generation mobile technology, introduced family of standards for 3G termed as International Mobile Telecommunications-2000 (IMT-2000). It included systems like Universal Mobile Telecommunication System (UMTS), CDMA 2000, GSM Evolution-EDGE [1]. International Telecommunications Union-Radio communications sector (ITU-R) specified a set of requirements for 4G standards, termed as International Mobile Telecommunications-Advanced (IMT-Advanced). IMT-Advanced mobile systems provide access to wide range of telecommunication services including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based [2]. In 2012, ITU approved the specifications for IMT-Advanced, and determined that LTE-Advanced and Wireless MAN-advanced (WiMAX2) should be accorded the official designation of IMT-Advanced [3].

The 3rd Generation Partnership Project (3GPP) unites telecommunications standard development organizations, known as Organizational Partners. The scope of 3GPP is to prepare, approve and maintain globally applicable Technical Specifications and Reports for a 3rd Generation Mobile System based on the evolved GSM core networks, and the radio access technologies (i.e UTRA for Frequency Division Duplex (FDD) and Time Division Duplex(TDD) modes). The success of 3GPP subsequently lead organizations to the development of GSM, GPRS and EDGE technical specifications and reports. Recently it has completed the development of the 3GPP LTE and LTE-Advanced technical specifications and reports [4].

The 3GPP has developed specifications for mobile technologies from GSM to LTE-Advanced, differentiated by releases [5]. The first 3GPP release of the UMTS standard took place in 1999. Since then number of 3GPP radio access technologies and systems were released, each adding further functionality. 3GPP releases, their respective freeze year and Specifications are summarized in Table 4.1.

Each progressive 3GPP radio access technologies provides a high degree of continuity in the evolving systems by delivering higher data rates, quality of service and cost efficient. 3GPP introduced evolution of 3G System in 2008, Release-8 termed as Long Term Evolution (LTE) towards the need of IMT-2000. The advanced version of LTE termed as Long Term Evolution-Advanced (LTE-A) was introduced in Release 10 which satisfies the requirement for IMT-Advanced.

3GPP Release	**Technology**	**Freeze Year**
Release 99	Specified first UMTS 3G netowrks: W-CDMA	March 2000
Release 4	TDD	March 2001
Release 5	Introduced HSDPA	March - June 2002
Release 6	HSUPA,MBMS	December 2004 - March 2005
Release 7	HSPA+ Improvements to QoS and EDGE Evolution	December 2007
Release 8	LTE OFDMA, MIMO based radio interfaces	December 2008
Release 9	LTE Enhancements	December 2009
Release 10	LTE-A fulfills IMT-Advanced 4G requirements	March 2011
Release 11+	Further LTE Enhancements	September 2012

Table 4.1: 3GPP release of radio access technologies

To achieve the target data rate of LTE and eventually 4G, many new techniques are necessary. Multiple-Input Multiple-Output (MIMO) is one key technique among them because of its ability to enhance the radio channel capacity of cellular systems at no extra cost of spectrum.

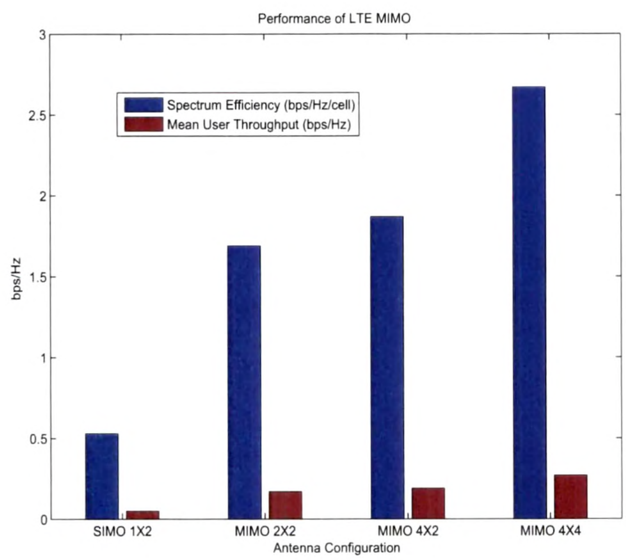


Figure 4.1: Performance of LTE MIMO with different antenna schemes

LTE-A downlink performance evaluation for MIMO configurations (2x2 and 4x4) are compared based on LTE Requirements [6]. As shown in Figure 4.1, Spectrum efficiency and Mean User throughput, increases as the number of antennas at transmitter and receiver increases in MIMO configuration. The Spectrum efficiency of SIMO with 1x2 configurations is 0.53 bps/Hz/cell and that of 2x2 is 1.69 bps/Hz/cell and 2.67bps/Hz/cell for 4x4. The Mean User throughput (bps/Hz) analysis is also shown. The results are for 20 MHz bandwidth, 64 QAM modulations and FDD mode.

4.2 E-UTRAN Architecture and Protocol Stack

The network architecture of LTE is as shown in Figure 4.2 comprises of following components [7](Chapter 2):

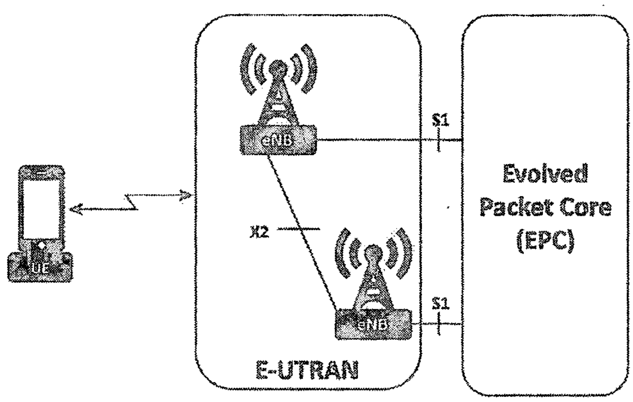


Figure 4.2: E-UTRAN Architecture

- User Equipment (UE): The internal architecture of the user equipment for LTE is identical to that in UMTS and GSM, which is basically a Mobile Equipment.
- Evolved-UMTS Terrestrial Radio Access Network (E-UTRAN): The E-UTRAN handles the radio communications between the mobile and EPC and consists of evolved base stations, called eNodeB. Each eNB connects with EPC by means of S1 interface and connected to nearby eNB by the X2 interface, which is mainly used for signaling and packet forwarding during handover.
- Evolved Packet Core (EPC): The EPC consists of components like Mobility Management Entity (MME), Serving Gateway (S-GW) and Packet Data Network (PDN) Gateway(P-GW).

The E-UTRA radio interface protocol architecture is as shown in Figure 4.3 consists of three layers [8]:

Layer 1: Physical Layer (PHY)

Layer 2: Medium Access Control (MAC)

Layer 3: Radio Resource Control (RRC)

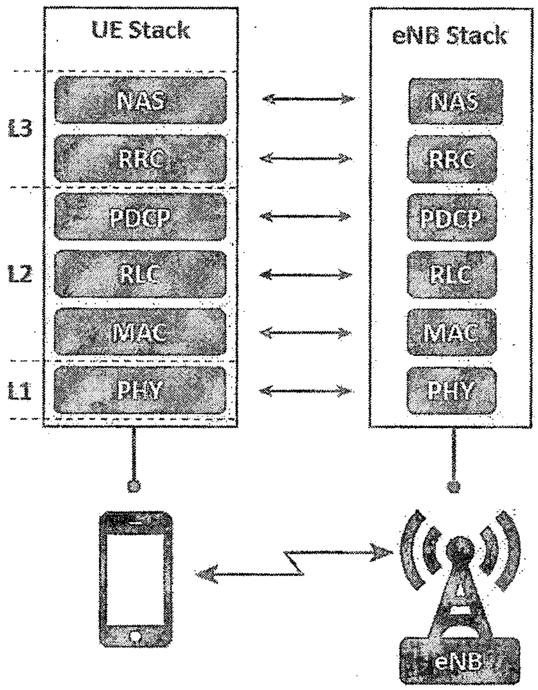


Figure 4.3: E-UTRA radio interface protocol architecture

The physical layer interfaces the MAC, sub-layer of Layer 2 and the RRC, Layer of Layer 3. The Physical (PHY) layer is the basis of base station-to-mobile device connectivity. The PHY interfaces with Layer 2 and Layer 3 and offers data transport services to higher layers. The multiple access scheme for the LTE physical layer is based on Orthogonal Frequency Division Multiplexing (OFDM) with cyclic prefix (CP) in the downlink, and on Single-Carrier Frequency Division Multiple Access (SC-FDMA) with cyclic prefix in the uplink.

The 3GPP TS 36.200 series describes the PHY Layer specifications. Layers 2 and 3 are described in the 3GPP TS 36.300 series. The services provided by each protocol stack and their features are listed below:

Non-Access Stratum (NAS) [9]

- Session management
- Mobility management
- Security procedures

Radio Resource Control (RRC) [10]

- System information handling
- Idle mode procedures handling
- Security management on radio interface
- NAS messages encapsulation and de-encapsulation and delivery to NAS protocols

Packet Data Convergence Protocol (PDCP) [11]

- User Plane (UP) path features: ciphering, robust header compression (ROHC)
- Control Plane (CP) path features: ciphering, integrity
- In-sequence delivery to higher layers
- Re-transmissions handling at handover

Radio Link Control (RLC) [12]

- Transparent Mode (TM) features: buffering
- Unacknowledged Mode (UM) features: segmentation / concatenation of SDUs, buffering
- Acknowledged Mode (AM) features: error correction handling through ARQ, segmentation / concatenation and re-segmentation of SDUs, buffering
- In-sequence delivery to PDCP, duplicate detection and discarding

Medium Access Control (MAC) [13]

- Mapping between logical channels and transport channels
- Interface towards PHY and RLC
- Logical channels multiplexing and priority handling
- Resource allocation and link adaptation
- HARQ and RACH processing
- Feedback creation and processing

PHY abstraction (MAC-PHY interface)

- Data transfer
- HARQ / DCI / UCI information exchange and feedback

- Sending of scheduling request
- Transport to Physical channels mapping

LTE downlink PHY processing accepts data and control streams from MAC Layer in the form of transport blocks. Transmission with MIMO is supported with configurations in the downlink with two or four transmit antennas in Release 8 and upto eight transmit antennas in Release 10 and two or four receive antennas in Release 8 and upto eight receive antennas in Release 10, which allow multi-layer transmissions with up to four streams or eight streams respectively [8, 14]. The 3GPP Physical Layer specification for the LTE and LTE-A radio technology is given in specification 36 series. The list of various Technical Specifications and Reports are given in Table 4.2.

Specification Number	Contents
TS 36.201	E-UTRA; LTE physical layer; General description
TS 36.211	E-UTRA; Physical channels and modulation
TS 36.212	E-UTRA; Multiplexing and channel coding
TS 36.213	E-UTRA; Physical layer procedures
TS 36.214	E-UTRA; Physical layer; Measurements
TR 36.912	Feasibility study for Further Advancements for E-UTRA (LTE-A)
TR 36.913	Requirements for further advancements for E-UTRA (LTE-A)

Table 4.2: 3GPP LTE Physical Layer Specifications and Reports

4.3 LTE Downlink Physical Layer

4.3.1 LTE Frame and Subframe Structure

In LTE, the uplink and downlink transmissions are organised into radio frames of 10ms, consisting of 10 subframes, each consisting of OFDM symbols. Two radio frame structures are supported:

- Type 1, applicable to FDD,
- Type 2, applicable to TDD.

In Frame Structure Type 1 (FDD), radio frame contains downlink or uplink subframes depending on link directions. The uplink and downlink transmissions have different bandwidths, i.e they are separated in frequency domain. Each radio frame is 10ms long and consists of 20 slots of length 0.5ms each, numbered from 0 to 19. Each slot of radio frame consists of 7 OFDM Symbols. OFDM Symbols consists of Cyclic prefix for timing and synchronization of signals. Detailed timing and samples of CP and OFDM Symbols are as shown in Figure 4.4.

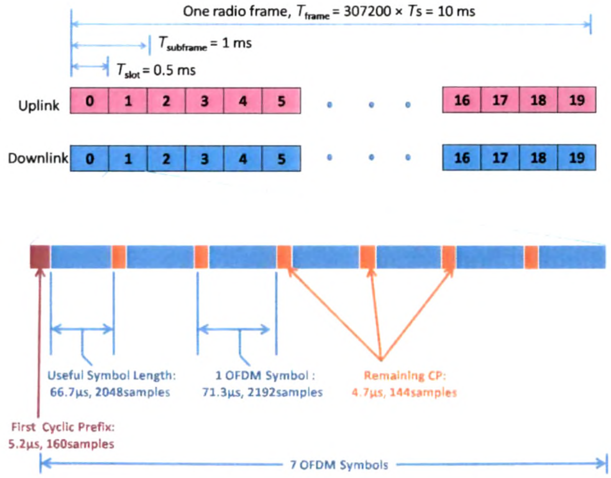


Figure 4.4: Frame Structure Type 1 (FDD)

4.3.2 Downlink Slot Structure

In Downlink, the transmitted signal in each slot of 0.5ms is described by a resource grid of $N_{RB}^{DL} N_{SC}^{RB}$ subcarriers and N_{symb}^{DL} OFDM symbols [14]. The parameters for Downlink resource grid for transmission bandwidth of 1.4MHz are listed in Table 4.3. For multi-antenna transmission, there is one resource grid defined per antenna port. Each element in resource grid is defined by the index pair (k, l) in a slot where k and l are the indices in the frequency and time domain respectively.

Symbols	**Definitions**	**Value**
BW	Transmission Bandwidth	1.4MHz
T_s	Basic time unit	$\frac{1}{15000X2048} seconds$
T_{frame}	Radio Frame Duration	307200 x T_s = 10ms
$T_{subframe}$	Subframe Duration	1ms
T_{slot}	Slot Duration	0.5ms
N_{Sym}^{DL}	Number of OFDM symbols in a downlink slot	7
N_{RB}^{DL}	Downlink bandwidth configuration	6
N_{SC}^{RB}	Resource block size in the frequency domain	12 subcarriers
(k, l)	Resource block size in the frequency domain	$k = 0$ to $k = N_{RB}^{DL} X N_{SC}^{RB} - 1$ $l = 0$ to $l = N_{symb}^{DL} - 1$
$\triangle f$	Sub carrier spacing	15kHz

Table 4.3: LTE Downlink Resource Grid Parameters

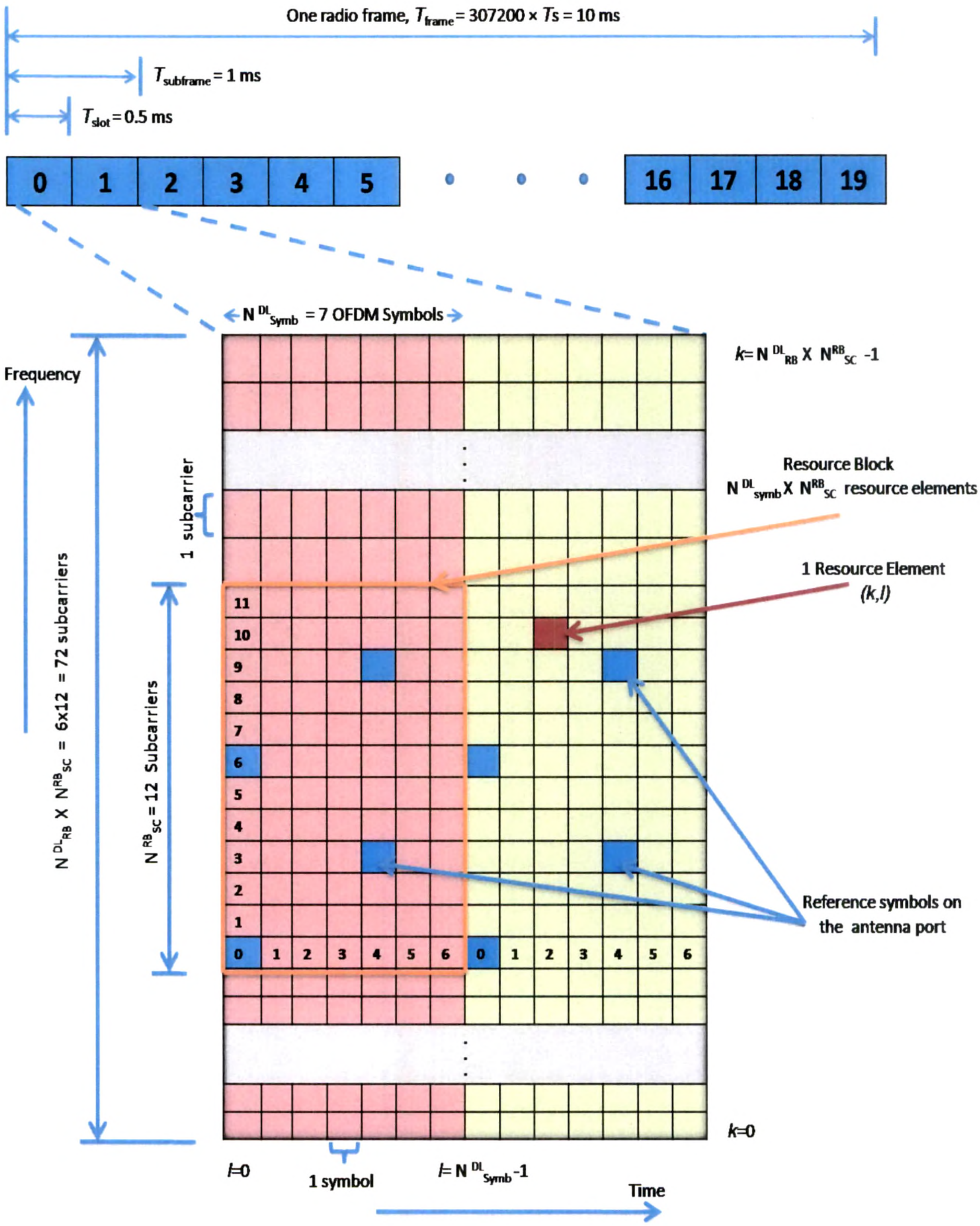


Figure 4.5: LTE Resource Grid

A physical resource block is made up of $N_{Sym}^{DL} X N_{SC}^{RB}$ resource elements, corresponding to one slot in time domain and 180kHz in frequency domain. For 1.4 MHz bandwidth with Normal Cyclic Prefix. As shown in Figure 4.5, one slot consists of 7 OFDM symbols in time domain and 12 consecutive subcarriers in frequency domain.

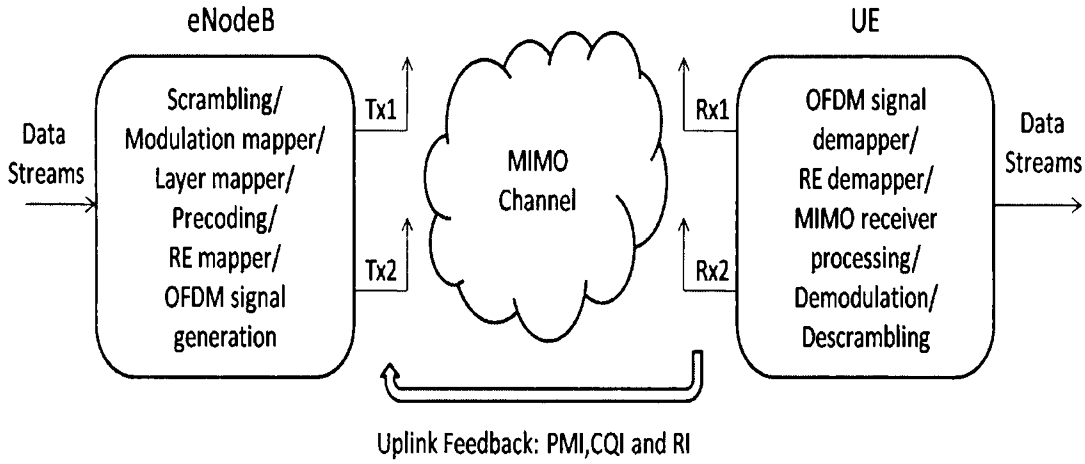


Figure 4.6: LTE Physical Channel Processing with Uplink Feedback

4.3.3 Downlink Physical Channel Processing

LTE physical layer is highly efficient for conveying both data and control information between an eNB and UE. Novel technologies such as multiplexing techniques, MIMO antenna schemes, duplexing schemes, flexible bandwidth, AMC schemes are employed to improve performance [14]. The uplink feedback values Channel Quality Indicator (CQI), Rank Indicator (RI) and Precoding Matrix Indicator (PMI) are calculated at the receiver, and is feedback to the eNodeB. The CQI performs selection of modulation scheme (QPSK, 16-QAM or 64 QAM). The RI gives information about the useful number of layers for layer mapping and PMI gives information regarding precoding matrix for the precoder [15–17].

Figure 4.6 shows LTE Downlink Physical channel processing for system with two antennas at eNodeB and UE each. The Physical channel processing consists of Scrambling, Modulation, Layer Mapping, Precoding, Resource Element Mapper and OFDM signal generation. The Layer Mapping and Precoding are for Multi-Antenna Processing. The MIMO Processing in Physical Downlink Shared Channel (PDSCH) Channel is briefly described in Figure 4.7.

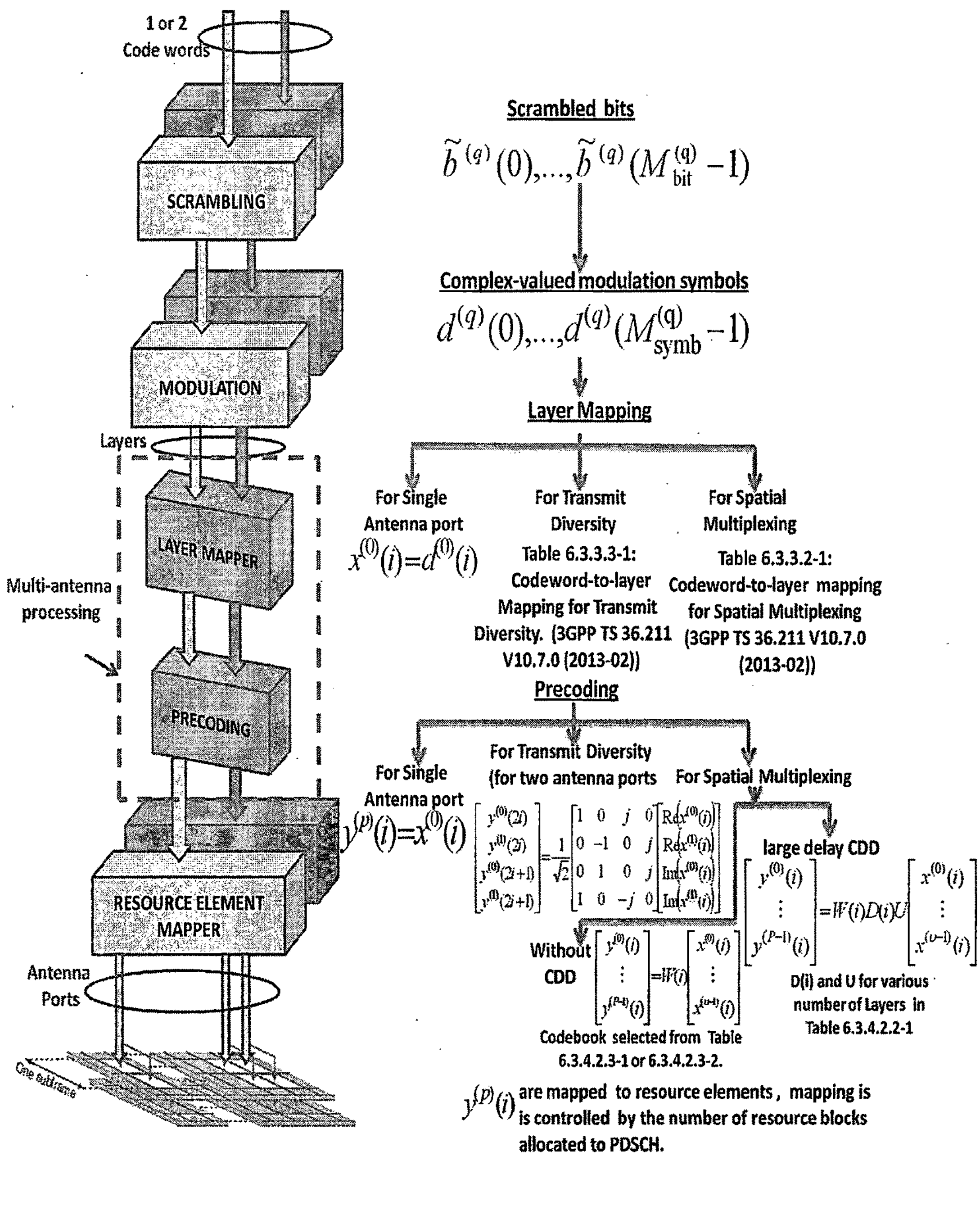


Figure 4.7: Downlink Physical Layer Processing

4.4 MIMO Downlink Transmission modes

MIMO technology is based on transmitting and receiving data streams with multiple antennas, utilizing uncorrelated communication channels. MIMO performance depends on number of parameters like number of transmit and receive antennas, reference signals, channel estimation techniques and feedback parameters from UE to eNB. LTE R8 and R9 support MIMO technology with upto 4 transmit and receive antennas in downlink. Release 10 extends MIMO support with upto 8 transmit and receive antennas. 3GPP LTE/LTE-A defines nine multi-antenna transmission modes (TMs) [18–21], listed in Table 4.4.

Mode	Release	Description
1	R8	Single Antenna Transmission
2	R8	Transmit Diversity
3	R8	Open Loop Spatial Multiplexing
4	R8	Close Loop Spatial Multiplexing
5	R8	Multi-User MIMO
6	R8	CLSM-Single Transmission Layer
7	R8	Beamforming
8	R9	Dual Layer beamforming
9	R10	Eight Layer Spatial Multiplexing

Table 4.4: LTE Transmission Modes

LTE/LTE-A supports various MIMO Transmission modes. The two main multi-antenna techniques, which have different performance gains and which are implemented in different was are discussed below.

4.4.1 Transmit Diversity

Transmit Diversity mode achieves Spatial Diversity by transmitting redundant information sequences from multiple antenna ports. It uses only one codeword and the number of layers are equal to the number of antenna ports. Transmit Diversity uses Alamouti like coding for transmission of codewords. This mode is suitable for cell edge where the channel condition is complex and interference is large, or high-mobility or for low SNR situations [22]. Figure 4.8 shows 2x2 Transmit Diversity Transmission mode.

4.4.2 Spatial Multiplexing

Spatial Multiplexing mode achieves higher bit rates by transmitting multiple parallel data streams. It uses one or two codewords and the number of layers is less than or equal to number of antenna ports. The number of layers in Spatial multiplexing depends on the MIMO channel Rank. It is suitable for high UE mobility, for good channel conditions and provides high data transmission rate.

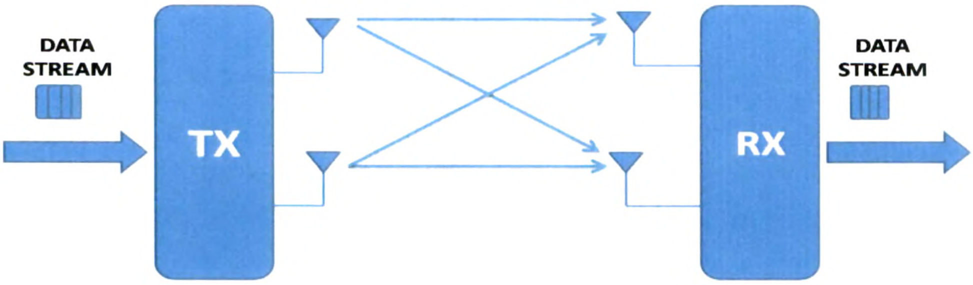


Figure 4.8: 2x2 Transmit Diversity Transmission Mode

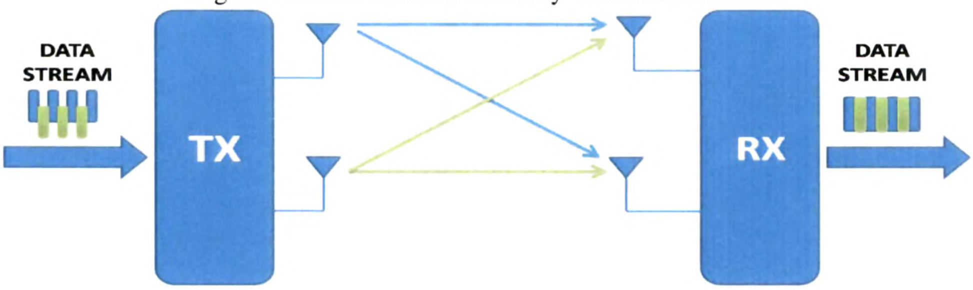


Figure 4.9: Open Loop Spatial Multiplexing

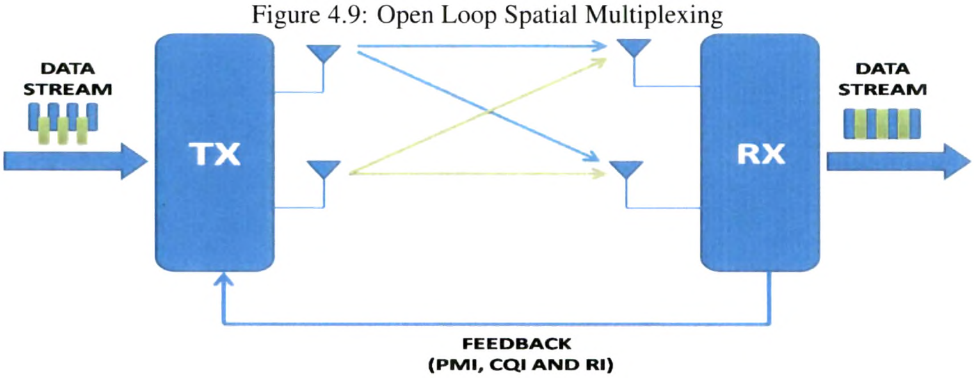


Figure 4.10: Close Loop Spatial Multiplexing

Figure 4.9 and 4.10 shows the concept of Open-Loop Spatial Multiplexing (OLSM) and Close-Loop Spatial Multiplexing (CLSM) Transmission modes respectively. The term closed loop in CLSM refers specifically to the loop that is created by feeding back the CQI, PMI and RI to eNB.

4.5 LTE-A Downlink Link Level Simulator

Vienna LTE-A Downlink Link Level simulator is a MATLAB-based link level simulation environment for 3GPP-LTE-A. The open source code of the simulator is available under an academic non-commercial use license [23, 24]. The LTE-A link level simulator consists of transmitting eNodeB, receiver User Equipments (UEs), a downlink channel model over which only the Physical Downlink Shared Channel (PDSCH) is transmitted, signaling information and an error-free uplink feedback channel with adjustable delay as shown in Figure 4.11. The eNodeB and UE are linked by the channel model, which is used to transmit the downlink data. The performance of Link Level Simulation can be analyzed using Bit Error Rate (BER), Block Error Rate (BLER) and Throughput (Mbps). The MATLAB-based Downlink Physical Layer (Link Level) simulator v1.1 [25, 26], consists of main files for performing simulation, saving and plotting the results, as listed in Table 4.5. The LTE-A simulator are implemented in MATLAB and require Communication Toolbox and Signal Processing Toolbox.

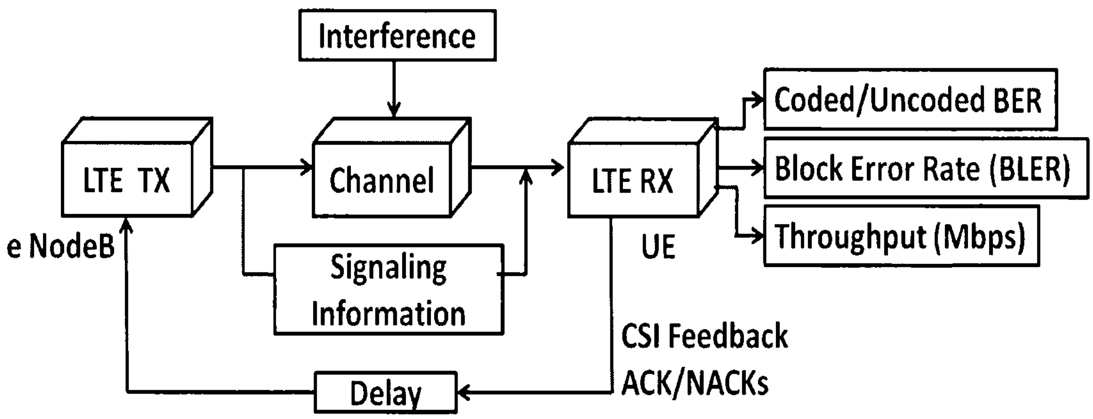


Figure 4.11: Structure of Link Level Simulator

Simulation Procedure	**MATLAB Files**
Run LTE Simulation	LTE_ sim_ main
Parallel Simulation	LTE_ sim_ main_ par
Normal Simulation	LTE_ sim_ main_ single
Plot Results	LTE_ sim_ result_ plots
Load Parameters	LTE_ load_ parameters
Load dependent Parameters	LTE_ load_ parameters_ dependent
Generate dependent Parameters	LTE_ load_ parameters_ generate_ elements

Table 4.5: LTE-A Downlink Link Level Simulator General Files

4.5.1 LTE Transmitter

LTE downlink transmission is based on Orthogonal Frequency Division Multiplex Access (OFDMA). The LTE downlink physical resources are represented by a time-frequency resource grid in which each resource element corresponds to one OFDM subcarrier during one OFDM symbol interval. These resource elements are grouped into Resource Blocks (RBs) as shown in Figure 4.5. Physical Downlink channel processing for LTE-A is briefly discussed in Section 4.3.3. The LTE Downlink Transmission steps and their related MATLAB function files of LTE-A Downlink Link Level Simulator are listed in Table 4.6.

Steps for LTE Transmitter	Matlab Files, functions and parameters
Generation of the transmit signal	LTE_TX
Read pregenerated reference signals	LTE_common_gen_Reference_Signal
Generation of other channels	LTE_common_gen_PBCH, LTE_common_gen_PDCCH
Generation of synchronization signals and Initialization of signals	LTE_common_gen_Synchronization_Signal
Scheduler	UE_MCS_and_scheduling_info
Add the scheduler information to the downlink channel	UE_MCS_and_scheduling_info(uu)
Get what HARQ process was assigned to this TX	UE_output(ue_numb).HARQ_process
Get the number of data and coded bits from the scheduler	UE_MCS_and_scheduling_info(uu). N_coded_bits(cw)
Generate data bits	tx_data_bits
Coding of the bits	LTE_tx_turbo_encode, LTE_tx_turbo_rate_matcher, LTE_tx_DLSCH_encode
Scrambling of the bits	LTE_common_scrambling
Symbol mapping	LTE_params.SymbolAlphabet
Layer mapping	LTE_common_layer_mapping
Determination of Codebook index	LTE_common_gen_8TX_codebook
Pre-Coding	LTE_precoding, LTE_tx_precoding, LTE_common_get_precoding_matrix
OFDM symbol assembly	CHmapping, PrimMapping and SecMapping
Zero padding, IFFT, add CP	LTE_params.Index_TxCyclicPrefix
Mapping of antenna port to antenna	LTE_map2antenna

Table 4.6: LTE Transmitter Steps and related MATLAB Function Files

4.5.2 Channel Model

The LTE-A Downlink Link Level Simulator supports block and fast-fading channel filtering. In the block-fading case, the channel is constant during the duration of one subframe (1 ms). In the fast-fading case, time-correlated channel impulse responses are generated for each sample of the transmit signal. The frequency-selective channels are modeled by the ITU and 3GPP Power Delay Profiles (PDPs). The LTE-A Link Level Simulator supports various channel models as listed in Table 4.7: The channel models are as defined for the ITU-R evaluation of IMT-2000 [27].

Channel Models	Abbreviations
VehA	Vehicular A
VehB	Vehicular B
PedA	Pedestrian A
PedB	Pedestrian B
PedBcorr	Pedestrian Correlated B
AWGN	Additive White Gaussian Noise
flat Rayleigh	Rayleigh Flat Fading
flatraycorr	Rayleigh Flat Fading Correlated
TU	Typical Urban
RA	Rural Area
HT	Hilly Terrain
Winner-II	Winner Channel Model

Table 4.7: Channel Models

The MATLAB files which generate the channel matrix and channel noise are listed in Table 4.8

Channel Model	MATLAB Files
Generate channel matrix	LTE_channel_matrix
Filter the output of transmitter and add noise	LTE_channel_model

Table 4.8: LTE Channel Model Generation MATLAB Function Files

4.5.3 LTE Receiver

Each UE receives the signal transmitted by the eNodeB and performs the reverse physical-layer processing of the transmitter. The Receiver processing consists of steps as shown in Table 4.9. LTE-A requires UE feedback to adapt the transmission to the current channel conditions. The LTE-A standard received signal specifies three feedback indicators for that purpose: CQI, RI, and PMI. The CQI is employed to choose the appropriate Modulation and Coding Scheme (MCS), such as to achieve a predefined target BLER, whereas the RI and the PMI are utilized for MIMO pre-processing.

Steps for Receiver	**Matlab Files and Parameters**
Receive signal, demodulate and decoding	LTE_ RX
Introduce carrier frequency offset	LTE_ params.introduce_ frequency_ offset
Read pregenerated reference signals	LTE_ params.Reference_ Signal
Generation of synchronization signals and Initialization of signals	LTE_ params.usePBCH, LTE_ params.usePDCCH, LTE_ params.Sync_ Signal
Carrier Frequency Offset Compensation	LTE_ rx_ freq_ sync
Remove CP, FFT, remove zeros	LTE_ params.Index_ RxCyclicPrefix LTE_ params.NfftCP , fft
Disassemble reference symbols	RefMapping
extract the signal on pilots positons	
Channel and noise estimation	LTE_ channel_ estimator
Disassemble symbols	CHmapping, PrimMapping and SecMapping
Perform detection	LTE_ detecting
Undo layer mapping	LTE_ get_ user_ layers
Demapper	LTE_ demapper
Descrambling of the bits	LTE_ common_ scrambling
Decoding of the bits	LTE_ rx_ DLSCH_ decode LTE_ rx_ turbo_ decode, LTE_ rx_ turbo_ rate_ matcher
Precoding feedback calculation	LTE_ feedback

Table 4.9: LTE Receiver Steps and related Matlab Function Files

The MATLAB based Vienna LTE-A Link Level Simulator is briefly discussed in this section. The Simulator is used is this research work to carry out the performance analysis in terms of BLER and Throughput for various MIMO Transmission Modes. The Simulation results and concluding remarks are presented in following section.

4.5.4 Simulation Results

Throughput Analysis of various MIMO Antenna configuration for LTE-A Downlink Physical Link Layer is as shown in Figure 4.12. Throughput of LTE-A Link layer increases as the number of antenna increases from 2x2 to 4x4 and to 8x8. Comparative Performance analysis for various MIMO Transmission modes were performed using MATLAB based LTE-A Link Level Simulator. Table 4.10 shows the Simulation Parameters used for the simulation.

As shown in Figure 4.13 (a) the SISO is compared with Transmit Diversity Scheme for 2x1 and 4x2 antenna scheme. At 30dB, throughput of SISO is 5.043 Mbps which is higher that that of 2x1 (4.869Mbps) and 4x2 (4.616 Mbps).

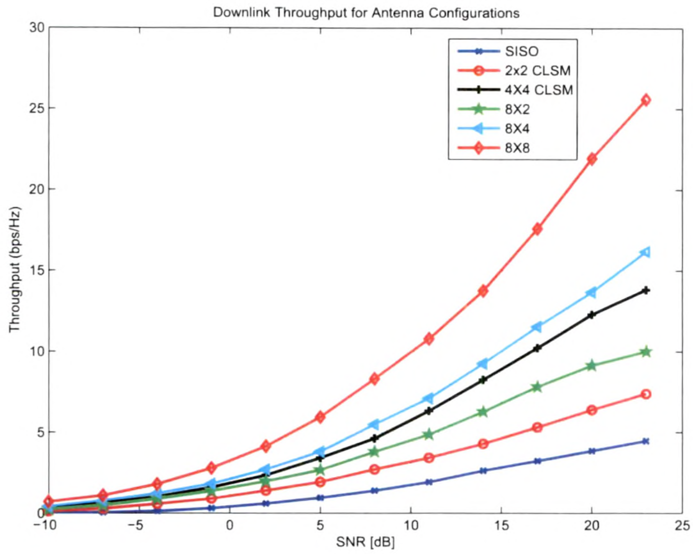


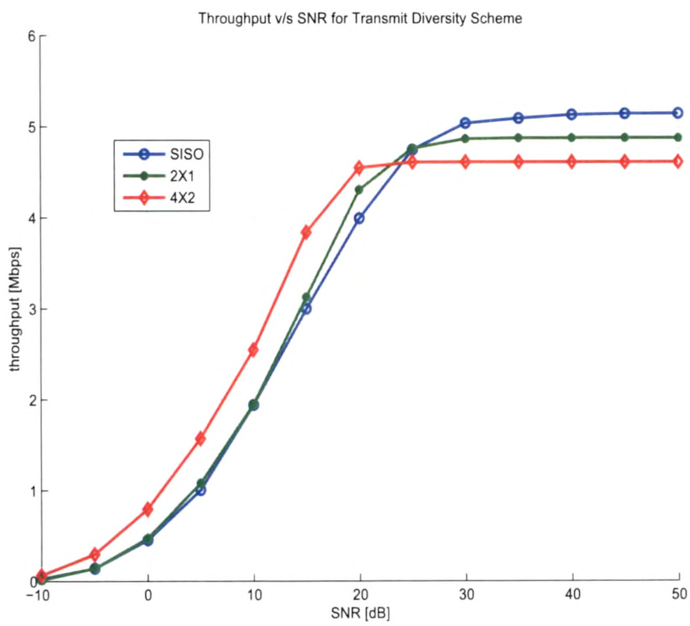
Figure 4.12: Throughput v/s SNR for MIMO antenna configuration in LTE-A

But when we compare Block Error Rate as shown in Figure 4.13 (b), 4x2 Transmit diversity has lowest BLER of $8X10^{-3}$ as compare to 2x1 ($66X10^{-3}$) and SISO ($194X10^{-3}$), at 0dB. Hence, as we increase the number of antennas at transmitter side the throughput decreases, but BLER increases as compare to SISO case.

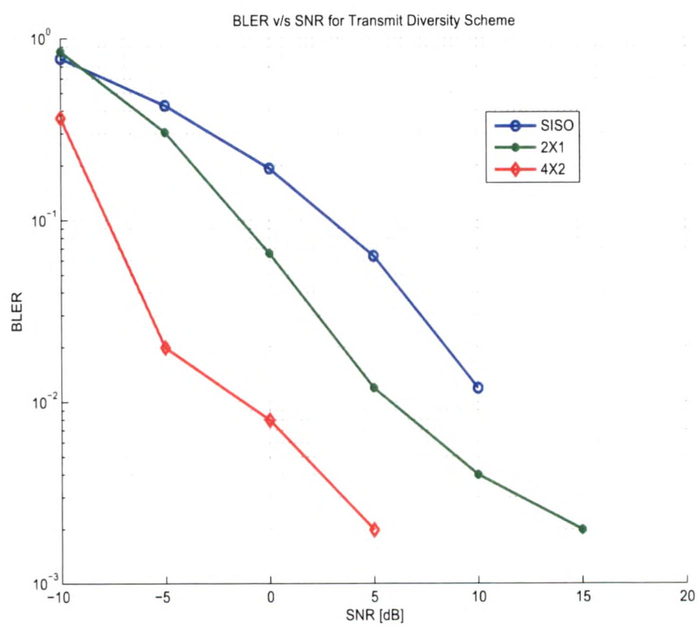
As shown in Figure 4.14 (a) the SISO is compared with OLSM and CLSM Scheme for 2x2 antenna scheme. Throughput of SISO System is lower when compared to OLSM and CLSM due to the effect of Spatial Multiplexing Gain. At 30 dB, throughput of SISO is 5.043 Mbps whereas that of OLSM is 9.257 Mbps and CLSM is 9.396 Mbps. The CLSM scheme has higher throughput due to the feedback indicators which gives information regarding channel conditions, rank and precoding indicators to the eNB. But when we compare the BLER as shown in Figure 4.14 (b), CLSM has lowest BLER as compare to SISO and OLSM. At 0 dB, BLER of CLSM is $3.745X10^{-3}$, for OLSM $12.92X10^{-3}$ and of SISO is $194X10^{-3}$.

Hence, Throughput of OLSM Scheme is higher as compare to SISO, but at high SNR the TxD has lower throughput compare to SISO. Spatial Multiplexing and TxD have lower BLER when compared to SISO.

As shown in Figure 4.15 (a), the SISO is compared with both Transmit Diversity and OLSM for 2x2 antenna scheme. At 30 dB, throughput of OLSM (9.257 Mbps) is highest when compared to TxD (4.88 Mbps) and SISO (5.043 Mbps). But when we compare BLER as shown in Figure 4.15 (b), 2x2 TxD has lowest BLER of $4X10^{-3}$ as compare to OLSM which has $12.929X10^{-3}$.

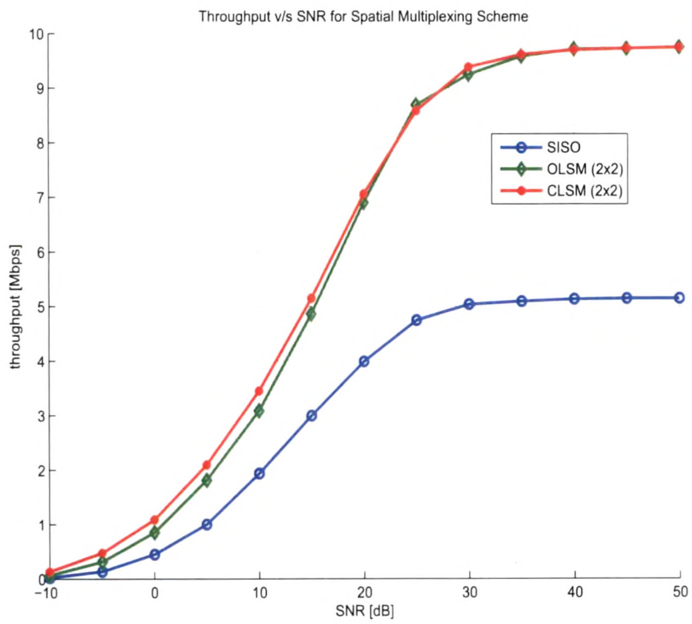


(a) Throughput for Transmit Diversity

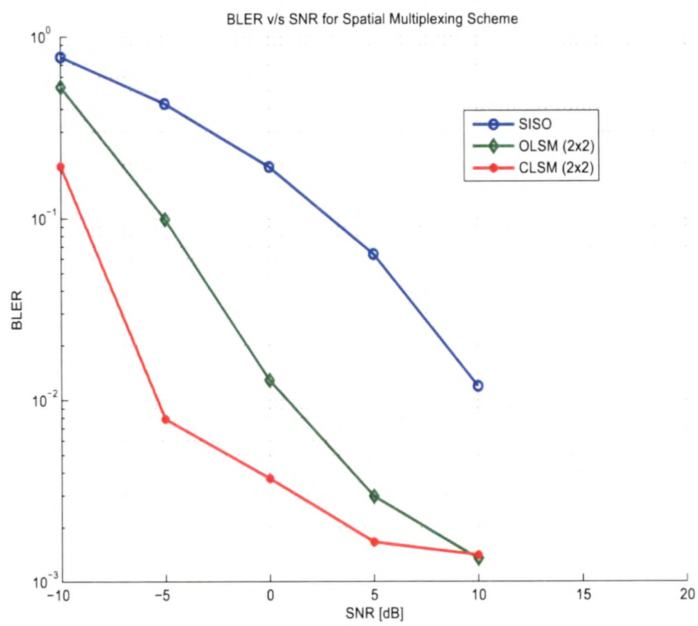


(b) BLER for transmit diversity

Figure 4.13: Throughput and BLER for Transmit Diversity

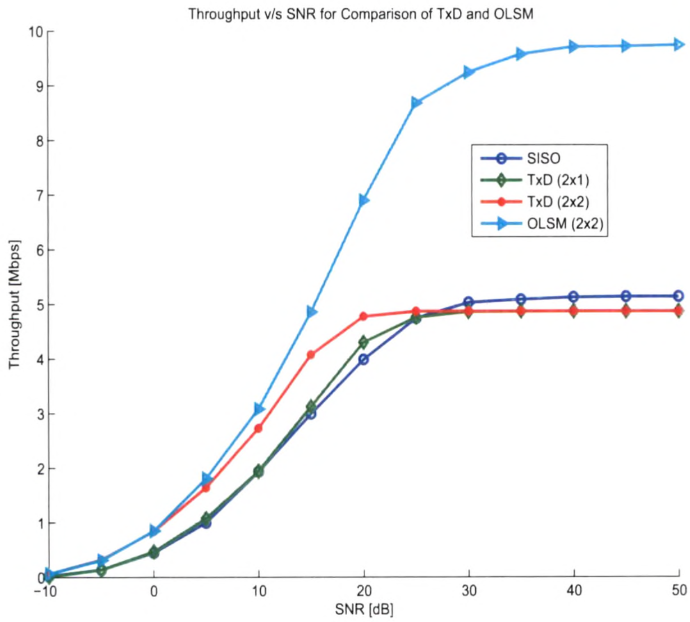


(a) Throughput for OLSM

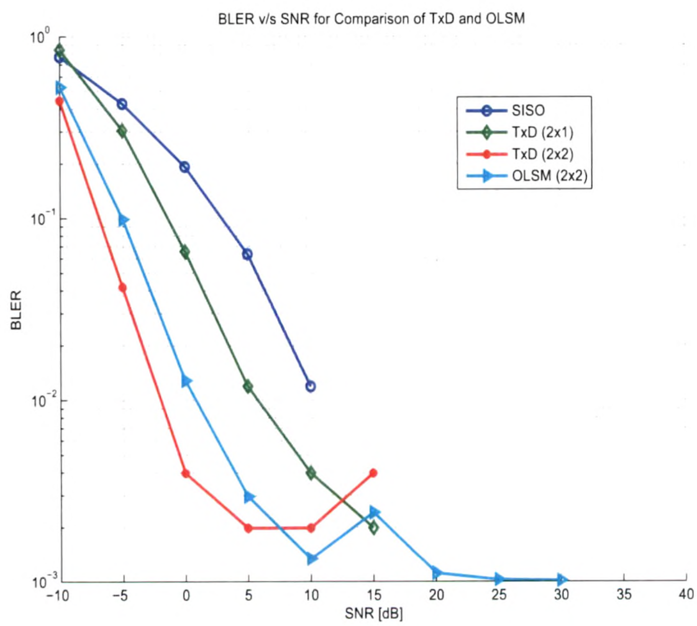


(b) BLER for OLSM

Figure 4.14: Throughput and BLER for Spatial Multiplexing



(a) Throughput for TxD and OLSM



(b) BLER for TxD and OLSM

Figure 4.15: Throughput and BLER for Transmit Diversity and Spatial Multiplexing

Parameters	Value
Number of Sub frames	500
Transmission Bandwidth	1.4 MHz
Number of UE	1
Number of eNodeB	1
Sub-frame duration	1ms
Sub-carrier spacing	15 kHz
Channel Estimation	Perfect
TTI length	1 ms
OFDM Cyclic Prefix	Normal
Simulation Configuration	SU-MIMO
Antenna schemes	SISO, TxD, OLSM and CLSM
MIMO receiver	ZF (Zero Forcing)
Channel Model Filtering	Block Fading
Channel type	Flat Rayleigh
Scheduler Type	Best CQI

Table 4.10: Simulation Parameters

Hence Spatial Multiplexing gives highest throughput, but the BLER is higher that that of TxD. The results discussed concludes the Diversity-Multiplexing Tradeoff for MIMO communication systems as discussed in previous chapter.

4.6 Results Summary

This section presents the summary of the results of Throughput and BLER for MIMO Techniques in LTE-A Physical Downlink Layer. Figure 4.16 shows the comparative analysis of TxD and OLSM MIMO Transmission modes for Rayleigh flat-fading channel and at SNR equal to 5dB. The tabular results are given in Table 4.11. It can be observed from the results that OLSM 2x2 has highest throughput of 1.81 Mbps as compare to SISO and TxD, but TxD 2x2 has lowest BLER of $2x10^{-3}$ when compare to other techniques.

Transmission Mode	Throughput	BLER
SISO	1.085	0.064
TxD (2x1)	1.009	0.012
TxD (2x2)	1.654	0.002
OLSM (2x2)	1.818	0.003

Table 4.11: Comparison of TxD and OLSM for SNR=5dB

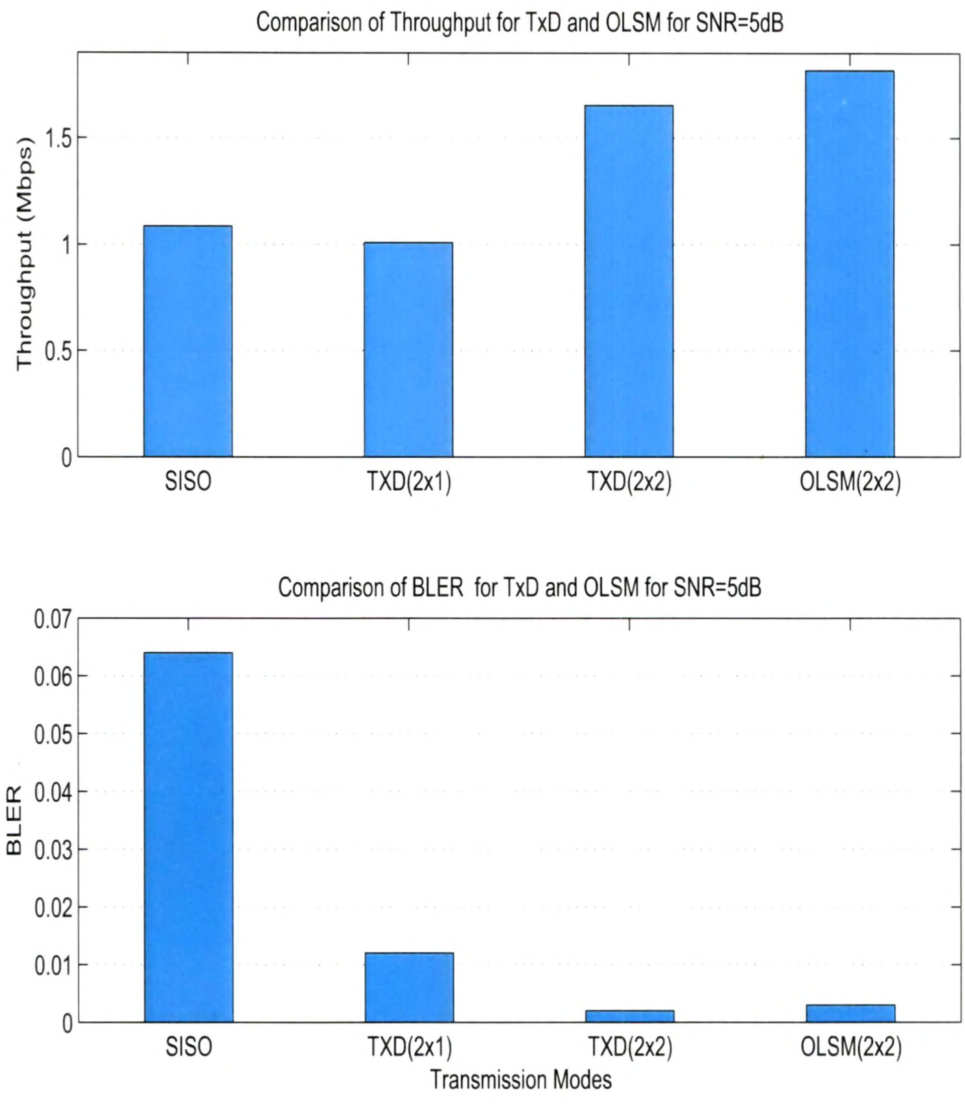


Figure 4.16: Comparison of MIMO Trasmission modes in LTE-A

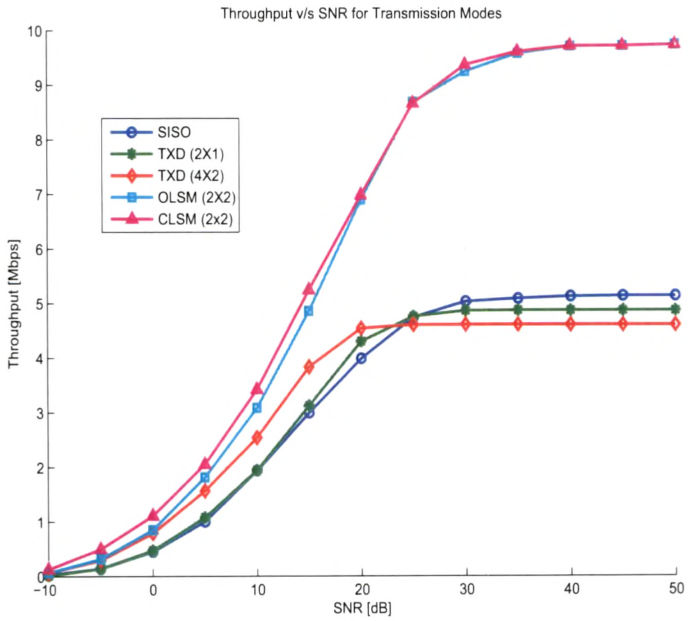


Figure 4.17: Throughput for Trasmission modes with Flat rayleigh

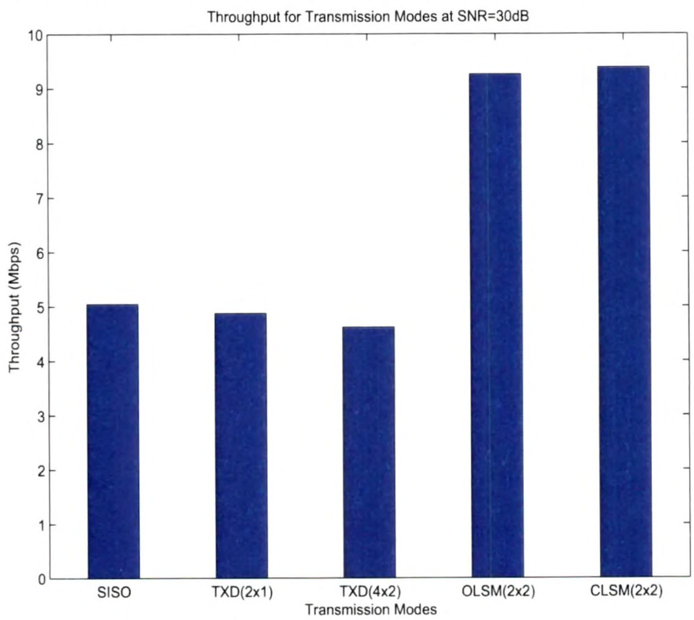


Figure 4.18: Comparison of Throughput for SNR=30dB

Hence we can conclude that OLSM offers high bit rates by transmitting independent information sequences over multiple antennas simultaneously. Whereas, low error rates is achieved with TxD by transmitting and/or receiving redundant signals representing the same information sequence. Comparative analysis of throughput v/s SNR for all MIMO Transmission schemes are as shown in Figure 4.17 and the throughput at SNR=30dB is as shown in Figure 4.18. It can be seen the CLSM scheme has highest throughput as compare to SISO ,TxD and OLSM.

4.7 Concluding Remarks

This chapter describes the LTE-A Downlink Physical Layer in detail. The MIMO transmission modes are explained in detail. Vienna LTE-A Link Level Simulator is briefly described. Simulation results for various MIMO Transmission modes is carried out. Spatial Multiplexing offers highest throughput, whereas Transmit diversity results into lowest BLER. Hence the tradeoff between transmit Diversity and Spatial multiplexing is verified for LTE-A Downlink Physical Layer with simulation results presented.