Maximizing LTE performance with MIMO systems

Author: Praveen Vunnam
Supervisor: Sven Nordebo
Examiner: Sven Nordebo
Date: 2016-11-18
Course Code: 5ED06E
Subject: Master thesis in electrical Engineering
Level: Master
Department Of Physics and Electrical
Abstract

The project explains Long Term Evolution (LTE) systems when used with Multiple-Input, Multiple-Output (MIMO) fulfill the growing demands in throughput and system robustness for the user. This is investigated by understanding the throughput capacity of LTE down-links in both spatial multiplexing and transmission diversity mode. The performance downgrades in LTE frame is analyzed. All the simulations are done in MATLAB. The simulations include Bit Error Rate (BER) being verified for values of Signal to Noise Ratio (SNR). MIMO systems use more than one antenna configuration for sending and receiving radio signals of the same frequency. The concept of beam forming may be utilized by MIMO systems. This is done by employing more than one antenna at both the ends namely transmitter (Tx) and receiver (Rx). The use of multiple antennas will achieve higher capacity and better cell coverage. MIMO technologies, when used in LTE, provide better down-link peak rates, cell coverage, and enhanced average cell throughput. LTE offers increased capacity while using standard antenna technique. This technique provides two vital aspects namely, spatial multiplexing (SM) and transmits diversity (TD). The project also explores the effect of different parameters namely, the speed of mobile station, the number of Multipath, Rician factor (K) on throughput is discussed and reported. The report evaluates the performance of LTE using MIMO in order to explain LTE system capacity, average cell throughput of LTE at different bandwidths and BER performance against SNR. The simulation outputs are shown as graphs and discussed.
Acknowledgment

My sincere thanks to My professor Sven Nordebo, for his directions and reviews for the betterment of thesis. His valuable suggestions has helped me to a great extent in achieving the fruitful results out of this thesis.

Special thanks to my wife Roja and my brother Siva, for their continuous support that kept me motivated through out this journey of research.

- Praveen Vunnam.
1 INTRODUCTION

The rapid increase in applications such as high definition video streaming, multimedia applications and web browsing, broadband cellular, social media, etc. are providing exciting opportunities for both consumers and service providers. These applications are highly data intensive and resource hungry giving rise to new kind of challenges in bandwidth delivery for mobile service operators. For coping with increasing bandwidth demands, operators make use of radio frequency (RF) bandwidth. However, RF is a finite resource and the telecommunications industry and service provider associations are looking for new options to overcome many of these limitations and challenges in RF (Stetler 2011). The increased demand for mobile broadband has motivated research for better data rates and Quality of Service (QoS) which resulted in Third Generation Partnership Project (3GPP). 3GPP project was involved in parallel projects namely Long Term Evolution (LTE) and System Architecture Evolution (SAE). The objective of both LTE and SAE is to define Radio Access Network (RAN), included in 3GPP in their Release 8. Evolved Packet System (EPS) is another name for LTE/SAE and this provided a revolutionary step for the wireless communications industry. The wireless industry was looking to offer very efficient, low-latency secure and packet optimized services and EPS provided the scope for fulfilling these important requirements. For this new system, the design parameters for main radio access are OFDM (Orthogonal Frequency Division Multiplexing) with MIMO (Multiple-Input, Multiple-Output). Data rates and performance is enhanced by these two techniques. Wireless network service providers use LTE to derive more throughputs from existing bandwidth. This is because LTE offers increased capacity using a standard antenna. LTE along with MIMO’s widespread deployment and optimization has multiple effects on LTE to further enhance data throughput. However, certain unique challenges are presented by MIMO and this requires network measurement and optimization techniques (PCTEL Inc 2011). These are also called a next generation wireless networks. MIMO systems in their transmission use multiple antennas to transmit (Tx). Signal is sent in transmit or Tx to the receiver (Rx) antenna on the same frequency. Wireless networks already use MIMO, which is commonly used in wireless networks. In next generation networks MIMO technology is a standard feature and plays a significant role in enhanced data rates and overall system capacity (3G Americas 2009). Network operates face challenges with MIMO. Cellular networks traditionally provide services under conditions of line-of-sight (LOS). MIMO functions under conditions that have rich scattering. Rich scattering refers to signals that will bounce around the environment. In conditions that have rich scattering, Tx signals take different paths in order to reach a user equipment (UE) at different times (PCTEL Inc 2011). Wireless cellular service providers must have their networks in optimal states to achieve higher throughput in LTE systems that target multipath rich scattering conditions for MIMO. Along with multipath conditions, signal to noise ratio (SNR) (Shannon 1948) must be high for each multipath signal. Thus in deriving good LTE performance, an optimized MIMO system will provide substantial throughput gains without additional expenses in adding spectrum (Ghosh et al 2010). MIMO is a more widely deployed antenna technique. LTE is widely accepted technology for advanced mobile broadband (4G). LTE is developed with a prime goal for better capacity and performance in "High Speed Packet Access" (HSPA) network environment that would eventually lead to a proper and
efficient communication, which means high data rates, low latency and broad range of spectral efficiency over a wide range of bandwidth. The radio resources in LTE are shared among active users while maintaining an adequate level of QoS with each user. In LTE operations, the basic MIMO features are available along with the techniques. Since, network conditions and UE capabilities differ greatly, a high degree of flexibility is required in MIMO systems in order to have maximum throughput. Further in MIMO each participating node can be configured to adapt in real-time transmission, understanding key transmission modes in LTE is important in conditions in which they are most useful (Sharma and Chopra 2014).

Proper communication is achieved by high data rates, low latency and broad range of spectral efficiency over a wide range of bandwidth. LTE due to its advantages is explored and studied as one of the key technology areas in next-generation wireless networks. LTE standard focuses on enhancing data throughput for each user by reducing delays, to improve flexibility in the spectrum and to minimize cost for both end users and operators. MIMO (multiple input multiple outputs) is one crucial technology in LTE that has the ability to gain required peak data-rate and to maximize channel capacity. The performance of LTE systems is enhanced by increasing its capacity which can be achieved through MIMO systems. MIMO has the ability to fulfill the growing demands in throughput and system robustness. The project investigates the throughput capacity of LTE down-links in both spatial multiplexing and transmission diversity mode. In this project, LTE which is the 4G wireless communication is taken as a reference frame. The LTE frame is analyzed for its performance downgrade. The simulations are done using MATLAB. The design and simulation of the OFDM system are done with cyclic prefix. The Bit Error Rate (BER) is checked by altering the Signal to Noise Ratio (SNR) value. OFDM system is investigated eliminating the cyclic prefix. LTE along with MIMO provides increased capacity while using standard antenna technique. The technique discussed in this project offers two vital aspects, Spatial Multiplexing (SM) and Transmit Diversity (TD). The aspects of SM and TD are examined for their effects in the throughput of the system. The project also discusses the effects of various parameters of such systems namely, the speed of mobile station, the number of Multipaths, Rician factor (K) to show the throughput.

1.1 Aims and Objectives

This project focuses on understanding LTE system and to maximize the performance of LTE using MIMO systems. The objectives are:

- Use MIMO and SISO systems to determine the capacity of LTE System
- At different bandwidths, obtain the average cell throughput of LTE system
- Study the effects of the efficiency of cells in multipath propagation conditions on LTE system
- Compare the BER performance of LTE system using MIMO Systems and SISO systems at different modulation techniques
1.2 Background

LTE along with MIMO plays a significant role in next generation wireless networks. LTE along with MIMO fulfills the growing demands in throughput and system robustness for the user. The project investigates the throughput capacity of LTE down-links in both spatial multiplexing and transmission diversity mode. LTE which is a 4G wireless communication is taken as a reference in this project. Performance downgrades in LTE frame are analyzed. The simulations are done in MATLAB. The cyclic prefix is used in the design and simulation of OFDM system. The Bit Error Rate (BER) is verified for many values of Signal to Noise Ratio (SNR). OFDM system is investigated eliminating the cyclic prefix. The configuration of MIMO system consists of two antennas to receive multiple data streams via different spatial paths, i.e. in the transmission of data streams the same frequency is used which is spread out in time. The concept of beam forming may be utilized by MIMO systems. This is done by using more than one antennas at both the transmitter (Tx) and receiver (Rx) sides for achieving higher capacity and better cell coverage. MIMO technologies when used in LTE provide more benefits like better down link peak-rate, wider cell coverage and improved average cell throughput. LTE offers increased capacity while using standard antenna technique. Two vital aspects are provided in this technique: spatial multiplexing (SM) and transmit diversity (TD). These two aspects are examined for their effects on throughput in the system. In this project the parameter effects namely, the speed of mobile station, Multipath numbers and Rician factor (K) on throughput is explored and analyzed. The report evaluates the performance of LTE using MIMO in order to explain LTE system capacity, average cell throughput of LTE at different bandwidths and BER performance against SNR. The outputs are shown as graphs and discussed.

1.3 Research Questions

The project attempts to answer the following questions:

- The importance of performance throughput in LTE systems
- The effects of channel capacity
- The effect of spatial multiplexing and transmit diversity in throughput performance
- The LTE performance and throughput in Rayleigh and Rician fading channel

1.4 Dissertation Outline

The report is organized into different chapters and sections. The introduction chapter provides a high level description of 3G, LTE networks and the importance of MIMO in LTE systems. The chapter on literature review provides a review of existing research and literature on next generation wireless technologies, cellular generations, a brief of LTE techniques and enabling technologies, a brief survey on LTE experiments and antenna configurations in MIMO. The chapter on theoretical foundations covers briefly the theory related to physical signal and channels in LTE, receive diversity, transmit diversity in MIMO and the technique of spatial multiplexing in MIMO. The design and
development chapter highlights the specifications and MATLAB model for the transmitter, channel and receiver. Finally, the results chapter present the output derived from MATLAB and discuss them to show the importance of MIMO with LTE systems.
2 LITERATURE REVIEW

In this chapter existing literature related to LTE and MIMO are reviewed for their performance benefits as explained by other researchers in this field. The resources are secondary in nature, and they include, journals, reports, white papers, textbooks, online articles, etc.

2.1 A Brief on Next Generation Network (NGN) Wireless Technologies

Cellular wireless networks available currently are deployed as homogeneous networks using the process of planned macro-centric approach. In the planned approach, the base stations are configured for maximum coverage and interference between base stations is reduced. In the case of homogeneous networks the cellular system has planned layout with a network of base stations (BS) and user terminals as a collection. In the planned network, all BS have transmission power levels equal for antenna patterns, noise in the receiver and identical connectivity to the data network in return. The network offers access to user terminals without restrictions by the BS and offers to serve the user terminals of the same number that carry data flows having the same QoS necessity. Network planning enables the choosing of locations of macro-BS. Here the settings of BS are configured to provide maximum coverage and contain the interference between them. In the case of an increase in traffic, there is a change in RF environment and the network depends on splitting of cells. A uniform user experience is obtained by additional carriers that overcome capacity and limitations in link budget. Therefore for operators a more flexible model is deployed for maximizing user experience for broadband with continuous availability in cost effective way (Khandekar 2010). Bhattacharyya and Bhattacharyya (2013) explains the next generation wireless networks include 4G or fourth generation mobile communication which is seen as a successor of 3G standards. 4G offers higher speed and better performance. 4G offers to provide speeds of 1 GBps in low mobility and minimum of 100 Mbps in high mobility. These speeds will provide the feature for users to access multiple services, including enhanced coverage for one device at reduced cost. Further there is no loss of signal and dependable wireless access is provided along without any loss or omission of networks. MIMO is used in 4G technology that involves multiplexing signal between multiple transmitting antennas and time or frequency. The generations of digital cellular evolution are shown in figure 1.

![Figure 1: Digital cellular generations](image-url)
The technology will easily work in existing infrastructure (mobile towers, antenna, etc) and hence, it eliminates cost for new hardware investments. The further network is also made available in remote locations more prominently as compared to earlier standards (Cole, nd). Bhattacharyya and Bhattacharyya (2013) explained the key features of 4G technology that include,

- One important feature is the detection and selection of a network. Participation in multiple networks simultaneously is possible when the mobile terminal features multiple radio technologies. Software defined radios also allow participation, thus providing the most appropriate parameters for service namely cost, QoS, capacity, etc. for applications.

- Handover is seamless and ensures continuity of service. Base stations have intra and inter technology handovers to provide zero or minimal interruption and no disruptions in service quality. This function requires support from transparent and continuous maintenance of active service instance and the inclusion of different technologies starting from Wi-Fi to OFDMA.

4G technology includes WiMAX and LTE having better performance compared to Wi-Fi. These two technologies offer wider coverage and better QoS. Broadband service in wireless is provided based on the point to multipoint connections. WiMAX and LTE offer broadband services in telecommunications. The user devices such as laptops, computers, smart phones, etc. connect to the internet using BS to control the access to the channel used by mobile subscribers. Further, WiMAX and LTE support both frequency division duplex (FDD) and time division duplex (TDD). Multiple users MIMO (M-MIMO) is another improved technology which involves the transmitting of data streams in simultaneous distinctive streams to the users belonging to the same frequency and time, which enhances the throughput capacity.

These two technologies offer wider coverage and better QoS. Broadband service in wireless is provided based on the point to multipoint connections. WiMAX and LTE offer broadband services in telecommunications. The user devices such as laptops, computers, smart phones, etc. connect to the internet using BS to control the access to the channel used by mobile subscribers.

In spite of the various benefits and advantages of 4G, there are also some challenges which must be managed. The challenges are in,

- **Security** objectives must be identified in this new mechanism and adequate protection must be provided for users (Rawat 2012).

- **Delay in handoffs** is also a major problem to QoS. When a handoff occurs, user experiences a noticable drop in QoS that shows a negative influence on applications and upper layer protocols (Varshney and Jain 2001).

- **Power issues in 4G devices**: 4G devices due to their large number of receivers and transmitters shows less battery backup. Hence, 4G devices need enhanced battery backup and this is recommended.

The application areas of 4G technology are widespread. For instance, multimode software application, which enables a mobile to get adjusted to different networks with data access at persistent
high speed net access that improves the expansion of the coverage area (Rawat 2012). The next application area is in the area of video network coding, which decreases in the number of packets needed in completing the transmission over defective networks that results in increased throughput and efficiency in video streaming applications and hence this is one of the beneficial application (Monpetit and Medard 2010).

2.2 An Overview of LTE

Long Term Evolution (LTE) is a wireless communication standard developed by 3GPP for use in new generation wireless networks. LTE offers the potential to have speeds to 10x in 3G for mobile devices (smart phones, notebooks, tablets, etc.) by the use of wireless hotspot. Technologies of 4G are designed for IP based voice, data and multimedia applications which require a speed of at least 100 Mbps and can scale up to 1 Gbps. In 4G standards, some of the leading cellular providers such as AT&T, Verizon, Sprint and others have deployed 4G technologies in their WiMAX networks. It is also interesting to note that most of the Android based smart phones are LTE capable and have built in 4G capabilities (Beal 2015). LTE is soon becoming the de facto mobile standard. Figure 2 below illustrates the use of LTE in next generation networks and supports all existing wireless systems.

![Figure 2: An illustration to show LTE support for NGN mobile access using IP core](image)

Multiple services are provided by multiple networks such as telephone networks, cellular telephone networks, data networks, etc which forms the traditional approach in communications. In the next generation network (NGN) all these functions are provided by using a flat all IP core to interconnect with multiple technologies for access. The all IP core provides QoS support for many applications and services. Routing management is provided by NGN access and ensures that the core views the mobile networks as another IP network. The different access to types will have seamless mobile handover between access types because as the IP network controls multiple
access technologies for security, authentication and billing. LTE is designed exclusively for NGN and is a de-facto mobile network standard. LTE offers an always on data experience by using the capabilities of NGN.

Across the world there is widespread adoption of GSM/CDMA which is the technology for 2G. For 3G services WCDMA, HSPA, EVDO, etc. are used. In the technological roadmap, LTE offers the next step because it evolves from 3G based on WCDMA (Wideband Code Division Multiple Access. The long term evolution of 3GPP as defined by WCDMA defines the LE in UMTS/HSPA cellular technology. This specification is known as the UMTS terrestrial radio access (E-UTRA) and this specification has evolved from UMTS terrestrial radio access network. This standard offers higher spectral efficiency along with high data rates and low latency (Dahlman et al, 2011). The performance provided by LTE in mobile access functionality up to 350 Km/h and it is tested for further speeds of up to 50 Km/h. Eylert et al, provided the data rates at peak range are from 100 to 326.4 Mbps on down-link and 50 to 86.4 Mbps on up-link depending on antenna configuration and depth of modulation (2009).

LTE is compatible with existing systems such as HSPA, UMTS and technologies based on GSM. Due to its compatibility for all existing GSM and HSPA operators, it offers a simple evolutionary path. This is offered by LTE’s complementary core network. Further LTE is developed to offer both FDD and TDD modes. This enables networks such as TD-SCDMA to have an easy change to TDD LTE (Scraser 2009).

2.3 A Brief on LTE enabling techniques/technologies

LTE systems have a number of enabling technologies in its evolution. The technologies include techniques such as MIMI, Turbo coding, OFDM and Dynamic Link Adaptation which have origins in telecommunications research. The techniques are briefly provided below:

2.3.1 OFDM

Ghosh and Ratasuk (2011) described the reasons for selecting OFDM with LTE. The single carrier FDM (SC-FDM) along with OFDM includes the following in its basic transmission scheme:

• Multi-path fading channel is made robust
• Efficiency in spectrum is high
• Less complexities in its implementation
• Transmission bandwidths are flexible
• Support for frequency selective scheduling, which is an advanced feature
• Transmission using MIMO
• Coordination of interface
The transmission scheme in OFDM is multicarrier. OFDM subdivides the transmitted information on the wideband channel. This subdivision on the wideband channel is done in order to align data symbols with multiple narrow-band orthogonal sub-channels. These are known as sub-carriers. This collection of sub-channels is possible when the frequency spacing between sub-carriers is small to a sufficient degree. This enables OFDM to offer a simple means of estimating channel frequency response which is based on transmitting data or reference signals which are known. A complexity frequency domain equalizer used can provide a good estimate of channel response at the receiver can recover the best estimate of transmitted signal. The response of the channel frequency at each sub-carrier is inverted by the frequency domain equalizer.

2.3.2 SC_FDM

Large variations in instantaneous transmit power is due to one of the drawbacks of OFDM. This means there is reduced efficiency in power amplifiers and this leads to higher consumption of power by the mobile terminal. In order to overcome these issues, one variant of OFDM namely SC-FDM (Single Carrier FDM) is chosen as a standard in LTE system for up-link transmission. Using discrete Fourier transform (DFT) for pre-coding, SC-FDM is implemented by combining the OFDM system (Ghosh and Ratasuk 2011). The fluctuations in transmit power is substantially reduced by the application of DFT based pre-coding. Most of the benefits in OFDM are featured in the resulting up-link transmission scheme. (Zarrinkoub 2014).

2.3.3 MIMO

In LTE systems, MIMO is a key technology which has ingrained in researching mobile communications. The techniques of MIMO explain the use of multiple antennas to fulfill demands in high throughput and peak data rates.

2.3.4 Turbo Channel Coding

Proakis (2001) explains that turbo coding is a result of the evolution of technology for convolutional coding used in previous criteria and this offers performance that has near channel capacity. This technique was introduced in 1993 for use in 3G UMTS and HSPA systems. The channel mechanism in turbo-coding for the process of user data is the only channel coding mechanism in LTE standard. In LTE, turbo coding allows the computational complexity of LTE turbo decoders without compromising on the performance of their decoders.

2.3.5 Link Adaptation

To respond to the dynamic nature of communications channel, link adaptation techniques are used. Link adaptation is one of the techniques in mobile communications for changing and adapting transmission parameters. Different modulation and coding techniques are used depending on channel quality. In a mobile communication system, channel dependent scheduling has close
relations to link adaptation. In channel dependent scheduling, many users can be accommodated to satisfy best QoS that may be available on the instantaneous channel condition (Zarrinkoub 2014).

2.4 A Survey on Long Term Evolution experiments

Sharma and Chopra (2014) provided different scheduling strategies along with performance, by taking into account the needs and requirements of users. The schedulers include,

1. Scheduler for maximum throughput: Maximum throughput (MT) is a strategy with the objective of achieving the maximum level of overall throughput. MT aims to achieve max output in given current transmission time interval (TTI).

2. Scheduler for sharing proportionally: In this scheduler, the ways to identify trade off between requirements of fairness and spectral efficiency is the scheme named proportional fair (PF). In order to serve uses in bad conditions, this scheme uses past average throughput as a weighting factor of expected data rate.

3. Modified Largest Weighted Delay First (M-LWDF): M-LWDF is an extension of LWDF which provides bounded packet delivering delay. In order to shape the behaviour of PF, MLWF uses information related to accumulated delay, thus assuring good balance in spectral efficiency, fairness and provisioning of QoS. This scheduler is developed to support multiple real time data users.

Sahoo et al, (2013) conducted simulation studies and explained the use of scheduling algorithms namely, FLS (Frame Level Scheduler) in which the algorithm is implemented on two different levels. The queue length and waiting time to service a queue is explained by EXP, and the balance between delay and robustness by LOG rule. Simulations were performed using LTE-Sim in the vehicular environment and performance analyzed for video traffic. The simulations were done for 10 to 60 users and the results showed FLS algorithm performs better for all parameters.

Alfayly et al (2012) in their research examined the performance of LTE algorithm for a user-group at various bandwidths considering VoIP to measure the impact on quality of experience (QoE). Simulation of LTE was developed by using LTE - SIM based on LTE scheduling algorithm namely PF, EXP-PF and M-LWDF in single cell scenario. Using a single cell in their experiment they developed four different scenarios namely static, pedestrian, vehicular scenarios and at different speeds. For real time flows, EXP-PF was considered. PF is not considered for VoIP applications because of its end to end delay and the two schedulers that have less end-to-end delay are MLWDF and EXP-PF. In another study related to a scheduling problem, Nie et al (2011) proposed a scheme is having two-level scheduling with support for QoS. Their study was aimed to support QoS and fairness guarantees for down-link traffic in WiMAX. The performance was analyzed for two-level scheduling scheme and results compared to using algorithms namely round robin and weighted round robin. Simulations were done in OPNET and it was concluded that QoS guarantee and fairness scheduling scheme for down-link traffic maximizes the throughput in down-link.

A system level simulator study was done to evaluate the performance of down-link LTE. In this
work, throughputs namely sector, user and Block Error Rate (BLER) were chosen as performance indicators and were analyzed. Results were obtained for three scheduling strategies namely Round Robin, CQI (Channel Quality Indicator) and PF scenarios, which has proved that CQI is the best among others (Iosif et al, 2013).

Biernacki et al, in their research (2013) of evaluating the three scheduling algorithms namely, PF, MLWDF and EXP-PF (Exponential/Proportional Fair) has proven that PF has the high packet delay and low throughput, however, in MLWDF and EXP-PF the packet loss ratio is almost same. Later, an extended version of EDF (Earliest Deadline First) and PF algorithms was proposed by Liu et al (2013), named Modified-Earliest Deadline First-Proportional Fair (M-EDF-PF), that is less complicated and has better efficiency in contrast with rest of the scheduling algorithms and apt for wireless systems. In another experiment by Al Jaradat et al (2013) based on PF, MLWDF and EXP-PF with LTE-sim in real-time conditions within distance of 1 kilo meter to check the interference, based on certain necessary conditions has concluded that MLWDF is the best.

In another simulation study two algorithms namely, Max Round Robin and Max Throughput algorithms were proposed. These two algorithms were proposed for their ability to high speed packet access to achieve higher capacity and fairness compared to conventional algorithms Max SNR, Round Robin and PF being the other three. In this case, users are not stationery and were situated randomly and the active users were changed for every instant. Results from simulation showed the two achieved higher values of efficiency in average cell output. (Sravani et al, 2013).

Another algorithm, energy saving based inter group proportional fair (EIPF), which was proposed by Keke et al, 2013 about LTE down-link services, where a transmission power is obtained according to data rate followed by IPF (Inter Group Proportional Fairness) scheduling algorithm, where the results has shown that the energy efficiency and throughput are better in EIPF in contrast to IPF.

2.5 What is Multiple Input, Multiple Output (MIMO)?

MIMO systems has multiple transmit antenna (Tx) and multiple receive antenna (RÂ­nx), where the transmission is over the same frequency and is widely used in wireless LAN networks (3G Americas 2009), which enhances LTE networks by offering good data rates and overall capacity to fulfill the promise in 3G and in 4G technologies. Outdated communications require additional conditions in order to have noise free communications but MIMO works well under rich scattering conditions, where the signals bounce around the environment, take different Tx paths to reach user equipment at different times to achieve better results. For this, telecom companies are more concentrated on SNR and good scattering environment for each signal. MIMO technology is most commonly implemented using an approach called single input, multiple outputs (SIMO) by employing antenna techniques. This adds to receive diversity and also in the method of multiple inputs single output (MISO) to provide variety in transmission. The techniques of SIMO are found since few decades but MISO techniques are used in most advanced cellular networks today. The techniques involve processes to boost the signal to noise (SNR) ratio for compensating degradations in the signal. Since RF signals pass through both Tx and Rx it weakens gradually due to disturbance from RF signals which minimizes SNR. This is especially found in concentrated environments, where the RF
signal continuously finds objects to change its path and degrade the signal. The loss in SNR can be compensated by multiple antenna systems. These systems combine different fading characteristics with signals because the route is different from each antenna. Multiple paths in Tx and Rx are taken by the methods SIMO and MISO to accomplish SNR gain (Ghosh et al, 2010). This is possible since different antennas send the same signal in a different manner and these signals attain NR gains. The SNR increases connection range to boost data rates by employing modulation schemes namely 16QAM or 64QAM instead of QPSK (Quadrant Phase Shift-Keying). The full benefits of LTE are achieved by the effect of throughput in MIMO technology. The configuration of multiplicative effect of throughput in MIMO is shown in figure 3.

For instance, if 2x2 (Tx = 2, Rx = 2) antenna configuration is required in order to achieve full benefits of LTE. The 2x2 configuration is effective because it doubles throughput for both the users. Throughput gains in MIMO are obtained by the following conditions:

- Designing the node according to MIMO settings
- Ensure that the user equipment is able to take full advantage of multipath conditions that are present
- Exploiting best scattering conditions (PCTEL Inc 2011).

In this way customer satisfaction is improved in MIMO systems. MIMO offers extended benefits in multiuser scenarios in the context of superior performance in terms of data rates in 3G wireless networks. Extensive research indicates that multi-user MIMO (MUMIMO) can be achieved in real time to have significant performance gains in existing wireless networks.
2.6 LTE Systems and Multi-User MIMO (MUMIMO)

Recently, worldwide there is an increase in wireless data due to the proliferation of smart phones and broadband enabled mobile devices. These reasons are driving the demand for much better user experience in terms of throughput performance. For instance in 2009 the same cellular service carriers experienced an increased average of 160% (3G Americas, 2013) and this demand is increasing. The industry forecasts indicate mobile data traffic is expected to double every year to have a global growth rate of 108% (Cisco VNI Forecast 2013). Optimized mobile network infrastructures fulfill the demands for large capacity. Duplicy et al (2011) explain emphasize that in the ongoing work in OFDMA networks, IEEE 802.16x (WiMAX) and 3GPP LTE are expected to cater to all performance demands. LTE is a 4G standard as defined by International Telecommunications Union (ITU) the data rate throughput is expected to reach beyond 100 Mbps in mobile applications and 1 Gbps for local wireless access. In order to realize this need researchers are investigating advanced features in future releases in standards such as WiMAX evolution and LTE systems. For instance, the project SAMURAI (Spectrum Aggregation and Multiuser MIMO Real World Impact) is being conducted to explore the possibility of high performance using techniques in the area of MUMIMO with the objective on practical implementation and deployment.

The use of multiple antennas and spatial surfacing improves reliability and higher spectral efficiency for users in spatial separation. The spatial resources transmit data with multiple users at the same time. Hence, the spatial dimension is beneficial for pre-coding in the down-link of the cellular system. In LTE and WiMAX the integral parts are in MIMO transmission techniques (Ghosh, et al, 2010).

In MUMIMO mode, the spatial-diversity of the propagation channel resources are overlapped with the same time frequency. This is done by exploiting the spatial diversity. The spatial streams intended to target terminals must be separated and must be ideally orthogonal in both sides. This is done to fully exploit MUMIMO transmission modes. The terminals that are targeted by intended spatial streams must be kept separated, preferably orthogonal at both transmit and receive sides. This arrangement is expected to significantly increase the theoretical performance gain of MUMIMO over SUMIMO. This increase in spatially correlated channels is reached with increasing number of transmit antenna at enhanced Node B (eNB) (Ribeiro et al 2008). The theoretical solutions derived are adapted in standard air interfaces.

The following section explains the design and development of simulation using MATLAB for LTE systems.
3 LTE AND MIMO: THEORETICAL FOUNDATIONS

In Shannon’s work related to channel capacity, data rates are restrained by the signal power available to the signal to noise ratio (SNR) in the received signal. Channel capacity relates to transmission bandwidths with data rates. In this situation with low bandwidth utilization or when the data rate is significantly lesser than the current bandwidth. Any increase in data rate will need an increased power in the received signal proportionality. On the contrary, when the bandwidth utilization is high the data-rate is equal or larger than available bandwidth. Hence, when data-rate increases there is a proportional increase in the power of received signal. For this purpose the overall power is increased by using multiple antennas at the side of the receiver which is also known as the receive diversity. Transmitter side uses multiple antenna, referred as transmit diversity. The transmitted power will be in the direction of the receiver because the approach of transmit diversity is based on beam formation by using multiple transmit antennas. The beam formation in transmit diversity has the potential to increase signal power and allows higher data rates. It is important to note data rates are saturated beyond a certain point because transmit and receive diversity can work only up to a certain point. To achieve high data rates the transmitter and receiver ends are provided with multiple antennas.

Transmission bandwidth is another factor that impacts the data rates that can be achieved in mobile communications. Wider transmission bandwidths are supported by the provisioning of higher data rates. The effect of multi-path fading is on the most important challenge in wider bandwidth transmission. By using the impulse response of radio channel the transmitted signal is filtered. A multi path fading channel in the frequency domain exhibits time varying channel frequency response. The domain content in transmitted signal is corrupted by the channel frequency response which has a reverse effect on data-rates which are achievable. The transmit power is increased for the purpose of adjusting the effects of selectivity in channel frequency and also for the purpose of achieving reasonable performance. Along with increasing the transmit power the data rates are reduced or the frequency domain distortions are compensated with equalization.

A number of channel equalization techniques are proposed to counter multi path fading. Adequate performance for transmissions above 5 MHz bandwidths has been shown by simple time domain equalization methods. However, in the case of LTE standards the complexities in time domain equalizers are large because bandwidth provision is wider in the range of 10-15 or 20 MHz. The problem of time-domain equalization is overcome by two approaches in wider band transmission, they are:

- Use of multi carrier transmission schemes. Here the signal with the wider band is represented as the sum of many numbers of narrow band orthogonal signals. For instance OFDM transmission is multi carrier transmission used in LTE standard.

- Transmission scheme with a single carrier is used. This scheme benefits from complexity frequency being low equalization which is given by OFDM. This is made in the absence of its high transmit power fluctuations. An example for this is in SC-FDM used as the technology in LTE standard for up-link transmission.
The higher order modulation scheme usage is one straightforward means of allowing high data-rates within the bandwidth of transmission. The bandwidth utilization is increased by using a high order modulation to indicate more number of bits in one modulated symbol. It is important to note that more utilization of bandwidth involves cost related to shortening minimum distance between symbols that are modulated and increased sensitivity to interference and noise as a result. The decision to use either lower or higher order modulation is decided by adaptive modulation and coding and other strategies related to link adaptation. Through this way the throughput is improved and data rates are achieved in communications links.

As mentioned earlier, MIMO methods are used to enhance mobile communications by two ways. The two ways are: the increasing of overall data rates and, the increase in dependability in communication links. The algorithms in MIMO used in LTE are categorized broadly into four areas namely receive diversity, transmit diversity, beam forming and spatial multiplexing. In the case of transmit diversity the redundant information is transmitted on different antennas. Transmitting in different antennas will not contribute to enhancements in the data-rates that are intended to be achieved rather the communication link becomes more robust.

In the case of spatial multiplexing, the LTE system transmits independent or non-redundant information using multiple antennas. In this MIMO scheme data rate is significantly boosted for any link given. The improvement in data rates is linearly proportional to transmit antenna numbers used in transmission. The LTE standard accommodates up to four transmit antennas to accommodate this data rate in down link specification. In the case of LTE advanced, the down-link transmission uses up to eight transmit antennas.

### 3.1 Physical Channels and Signals of LTE

In the case of LTE physical layer, the following concepts are explored for their importance. The LTE standard creates more effective architecture and a protocol stack that is streamlined. In LTE, as specified in 3GPP standards earlier dedicated channels are replaced by channels that are shared and there is a reduction in the total number of physical channels. The MAC layer is connected to the PHY by transport and physical channels are processed by the transceiver at PHY. For effectively transmitting on air interface the physical channel is specified by resource set of elements that carry information from the higher layers in the protocol stack. In data transmission involving down-link and up-link transmission, the system uses DL-SCH (Down-link Shared Channel) and UL-SCH (Up-link Shared Channel) respectively as the types of the transport channel. The physical channel carries the frequency resources for transmission of data in a specific transport channel. The corresponding frequency channel is mapped with each transport channel. Further, to physical channels and their corresponding transport channels, certain physical channels exist where the corresponding transport channels are absent. These are called control channels indicted by L1/L2 which is used in downloading control information (DCI) and required data is provided. The relationship between logical channels, physical and transport channels in LTE have different down link versus up link transmissions.
3.2 Physical Signals in LTE

In LTE systems, it can be found that between the shared physical channel a variety of physical signals are transmitted. This variety of signal includes signals for reference and synchronization. Physical signals do not contain information originating from higher layers but ma to specific resource elements used by PHY. The LTE signals include,

- **Reference Signal**: In frequency domain channel dependent scheduling is the most attractive feature in LTE standard. For instance to perform down link scheduling that is aware of actual channel quality, the mobile terminal provides the base station with information known as channel state information (CSI). CSI can be obtained by the measure of reference signals in down-link transmission. The reference signals are nothing but transmitted signals generated with sequence generators in synchronization in the transmitter and receiver. In the time frequency grid that has specific resource elements, these signals are placed. LTE specifies different types of up-link and down-link reference signals.

- **Reference Signals in down-link**: The functionality of estimating the channel is required to match and extract control of data which is supported by the down-link reference signals. The down-link reference signals are implemented in CSI measurements required for feedback on channel quality. Reference signals are of five types which are specified in down-link transmission. They are: Cell Specific Reference signals (CSR), Demodulation Reference Signal (DM-RS), Channel State Information Reference Signal (CSI-RS), MBSFN reference signal and positioning reference signal. CSRs are transmitted in every down-link sub-frame and are common to all users. The main function of DM-RS is to ease the problem of density associated with CSR while used for CSI measurements. This is used mainly only when over eight antennas are used. Hence, the use of CSI-RS becomes restricted to multi-user down link transmission given by mode 9. Finally LTE Release 9 introduced the positioning of reference signals. The positioning is introduced to support measurements and or estimating the location of any one terminal. The reference signal types are: cell specific reference signal, UE specific reference signals and CSI reference signals, which is of three types.

- **Reference Signals in up-link**: In LTE standard, two kinds of up-link reference signals are available namely DM-RS and Sounding Reference Signal (SRS). These two signals are based on Zadoff-Chu sequences. Zadoff-Chu sequences and are used for the generation of down-link primary synchronization signals (PSS) and up link preambles. Different UEs have different reference signals and these are obtained from parameters in base sequence with cyclic-shift.

- **Demodulation Reference Signals (DM-RS)**: Demodulation reference signals are as an element of up-link resource grid which is transmitted by UE. This is used by the receiver in BS in order to demodulate the up-link control (PUCCH) and (PUSCH) information. In PUSCH the normal cyclic-prefix is used. The fourth OFDM symbol positions the DSR signals. This OFDM symbol has 0.5 ms in each expansion slot and these slots continue throughout the resource blocks. The location of DSR in the case of PUCCH depends on the control channel’s format.
• **A Sounding Reference Signal (SRS):** SRS signals are used to enable BS to estimate up-link channel response at various frequencies. The responses are then transmitted on the up-link. The channel state estimated may be used for scheduling the dependent up-link channel. This indicates that the scheduler allocates the up-link band width with user data portions wherever the responses are encouraging for the channel. Other applications are available in SRS transmissions such as to determine timing and control of channel conditions in down-link when both channels, i.e., up-link and down-link are either reciprocal or identical to each other as with TDD mode.

• **Down-link Frame Structure in LTE:** There are two down-link frame structures specified by LTE. One down-link frame structure is known as type 1 frame applied to deployments involving FDD. The next frame or type 2 frame is applied in TDD deployments. There are ten sub frames in each frame and each sub frame has the feature of time frequency resource grid. The resource grid consists of three components namely, user data, channels for control or control channels, reference and synchronization signals. Figure 4 illustrates the structure of type 1 radio frame.

![Figure 4: Down-link FDD sub frame structure](image)

The duration of each frame is shown as 10 ms and composed of ten sub frame each of 1 ms duration. These sub frames are denoted by indices in the range of 0 to 9. Here each sub frame is sub-divided further into 2 slots each having time duration of 0.5 ms respectively. The slot is composed of six or seven OFDMs based on general or modified cyclic prefix. Within the first slot of each sub frame the DCI is placed. The content for PDCCH, PUFICH and PHICH are contained in DCI. This content is occupied by the first three OFDM symbols in each sub frame. This can be represented as L1/L2 control region because it contains information which is transferred to Layer 1 (PHY) from Layer 2 (MAC). Within sub frame 0, the PBCH is located which contains MIB. PSS and SSS (Secondary Synchronization Signal) are placed within the sub frames 0 to 5. The six resource blocks contain PSS and SSS signals along with PBCH signal are placed within these six blocks. These six blocks are centered on DC subcarrier. In addition to this, CSRs are also placed in each resource block, in each sub frame with specific pattern of time and frequency separations. The MIMO mode determines the pattern of placement of CSR signals and the number of antennas in use. The remaining resource elements in each
sub frame are allocated to user traffic data.

- **Up-link Frame Structure in LTE:** The up-link sub frame structure is almost similar to the down-link structure in some ways. The up-link frame structure is composed of 1 ms sub frames which are divided into two 0.5 ms slots. Corresponding prefix is used either six or seven SC-FDM symbols is composed in each slot. Data resource elements (PUSCH) contain the inner band resource blocks and this reservation is done in order to minimize out of band emissions. Different blocks are assigned to different users which ensure orthogonality among users in the same cell. In order to provide frequency diversity data transmission can hop at the slot boundary. At the edge of carrier band the control resources are placed. This placement is done along with inter slot hopping to provide frequency diversity. The data and control channels are interspersed with reference signals necessary for data demodulation.

### 3.3 Receive and Transmit Diversity in MIMO

In LTE systems, the technique for multiple antenna transmission depends on the use of more than single antenna at both ends, viz the receiver and transmitter. This is carried out using methods in advanced signal processing. However multiple antenna techniques add to computing complexities in the implementation. In spite of the complexities multiple antennas are used to provide enhancements in system performance and this also includes the capacity of the system. By utilizing multiple antennas, many different aims can be fulfilled at both the receiver and sender locations.

#### 3.3.1 Receive Diversity:

This is the most common and simplest multi antenna configuration at the receiver side, illustrated in figure 5.

![Figure 5: Receive diversity in MIMO](image)

Receive diversity uses the algorithm named Maximum Ratio Combining (MRC). In LTE standard this algorithm is used within mode 1 of the transmission. This transmission is dependent on single antenna. When single antenna is used in transmission, the transmission mode SISO (single input, single output). SISO systems are deployed using only one receiver antenna and in SIMO...
systems multiple antennas in receiver end are deployed. SIMO is also known as the combining method and there are two types which may be used in receiver end. These methods are MRC and selection combining (SC). In MRC method, multiple signals received are combined by computing their average to most probable estimates of the signal transmitted. In SC method, the highest SNR contained in the received signal is used to determine the transmitted signal. In MIMO technique, MRC is effective in fading channel where the interfering signals numbers is large and almost all signals demonstrate the same amount of strengths. In transmission over flat fading channels MRC works best. In LTE most of the wide band channels specified is subject to time dispersion which result in frequency selective fading response. Linear equalization is performed in order to counteract the effects of frequency selective coding. To make receive diversity more efficient linear equalization is done in the frequency domain.

3.3.2 Transmit Diversity:

Here more than one antenna is used. Many antennas are used for the purpose of introducing diversity in the transmitter side. The purpose of multiple antennas is to transmit surplus variants of the same signal through multiple antennas. This is one of the types of MIMO technique which is known as Space Time Block Coding (STBC). In this modulation, the symbols of STBC are represented in transmit antenna domains or time and space domain. This is done for capturing diversity provided by using many antennas in transmit.

SFBC (Space Frequency Block Coding) is another method which is related to STBC. SFBC technique is chosen for LTE standard in transmit diversity. The variation between both these techniques is that in the case of SFBC, the antenna and frequency domains are encoded. In the case of STBC encoding is done at antenna (space) in time domains. The diagram is shown in figure 6.

LTE systems make use of transmit diversity for second transmission mode. SFBC and frequency switched transmit diversity (FSTD) are involved or both two and four antenna transmissions respectively. TD contributes to enhanced robustness versus channel fading to improve link-quality and does not boost data-rate. Other MIMO modes namely, spatial multiplexing contributes directly to increased data-rates in LTE standards.

Figure 6: MIMO spaced frequency block coding in transmit diversity
3.4 Spatial Multiplexing:

In this technique of independent and complete data streams are simultaneously transmitted using each transmit antenna. Spatial multiplexing is used to transmit antenna ports for data. Simultaneously, transmission of various modulated symbols is possible over multiple antennas at the same sub-carrier in frequency. This implies that spatial multiplexing has the ability to directly increase the bandwidth efficiency and the resulting system has high bandwidth utilization. Spatial multiplexing provides maximum benefits and advantages when the transmissions using multiple antennas and are not correlated. In this situation, the multi-path fading in the communication links helps the actual performance. Since, multi-path fading de-correlates the signals received at every port of the antenna which is meant for receiving, spatial multiplexing transmission by using a multi-path fading channel can improve performance.

The performance can be realized in spatial multiplexing by solving a system of linear equations that describe the relationship between receive and transmit antennas. Figure 7 illustrates a 2 x 2 antenna configuration for spatial multiplexing.

Consider the MIMO equation,

\[
\begin{bmatrix}
Rx_1 \\
Rx_2
\end{bmatrix} = 
\begin{bmatrix}
h_{11} & h_{12} \\
h_{21} & h_{22}
\end{bmatrix}
\begin{bmatrix}
Tx_1 \\
Tx_2
\end{bmatrix} + 
\begin{bmatrix}
n_1 \\
n_2
\end{bmatrix} \tag{1}
\]

In this equation, at each sub-carrier the symbols s_1 and s_2 are transmitted over two transmit antennas respectively. Rx_1 and Rx_2 represent the received symbols at the same sub-carrier. The resulting linear combination weighted by channel matrix represented as H with additive white Gaussian noise (AWGN) denoted as n_1 and n_2.

In equation (1), h is the channel matrix which contains frequency responses for the channel at each sub carrier hij for any combination, where i is transmitted antenna and j are receiver antenna respectively. The transmit and receive antennas used are shown in matrix notation is represented the equation becomes,
In equation (2), $\vec{S}$ denotes the M dimensional vector of signals sent from the transmitter Tx. $\vec{S} = [S1, S2, ..., SM]$. The vectors denoted by $\vec{Rx}$ and $\vec{n}$ are vectors with N-dimensions that represent signals received and the corresponding noise signals. $\vec{Rx} = [Rx, Rx2, ..., RxM]; \vec{n} = [n1, n2, ..., nM]$. All the factors of vector $\vec{S}$ is part of single user. The multiplexing is done to various antennas for the data streams sent by this single user. This instance is known as Single User MIMO (SU-MIMO). Data streams that are multiplexed on different antennas for different users result in the system known as Multiple User MIMO (MU-MIMO).

It can be noted that OFDM is used for transmission in down-link and SC_FDM for up-link transmission. The MIMO schemes specify various transmission modes using multiple antennas. The LTE system is used to fulfill the following objectives:

- LTE offers improved system coverage and capacity
- Peak data rates are high
- Latency is low in user and control plane
- Operating costs are low
- Multi antenna support
- Band-width operations are flexible
- Integrates easily with existing systems (UMTS, Wi-Fi, etc)

Two fundamental components of UMTS architecture are covered in LTE requirements. These are EU-TRAN (Evolved Universal Terrestrial Radio Access Network) and EPC (Evolved Packet Code). The main focus of LTE is to boost mobile data rates it become useful to study LTE performance through MIMO systems in MATLAB.

MIMO technology is viewed as an ideal alternative for future wireless broadband services. MIMO offers to fulfill the desired needs for achieving throughput and robustness in the system. In LTE, MIMO is broadly used to obtain increased down-link peak rate, coverage of cells, as and the cell throughput average. There are two important facets of MIMO technique: Spatial Multiplexing (SM) and Transmit Diversity (TD). These two aspects are explored for understanding their effects on the systems throughput. The effect of parameters like the speed of mobile station, a number of multipath, Rayleigh fading channel and Rician fading channel (K) on the throughput of such system is studied. The review helps to estimate the throughput capacity of LTE down-link under the modes of SM and TD, all simulations are done using MATLAB. The design aspects of the experiment are explained in the next chapter.
4 DESIGN AND DEVELOPMENT

MATLAB is used in simulations due to its ability to provide insights by modeling PHY of LTE standard for the implementation requirements. MATLAB is used as development environment commonly because it offers to model of networks and performs the mathematical and numerical computation. In this project MATLAB is used along with Simulink in this project. Multiple antenna characteristics are studied for 2 x 2 antenna systems to determine throughput based on different factors. Rayleigh fading factor, Rician factor for bit error rate and SNR are also simulated and modeled. MIMO algorithms in LTE standards include the broad categories namely, a method for combining receiver, transmit-diversity, beam forming and spatial multiplexing.

Receiver combining methods are used in 3G mobile standards, wi-fi and WiMAX systems. It combines multiple versions of transmitted signal at receiver for improving performance. At the receiver end, the method of combing is of two types namely, MRC and SC as explained earlier. In selection combining or SC the complexities in MRC are ignored. The highest SNR in the signal received is used to estimate the signal transmitted. In MIMO the number of connection links equates exactly to the numbers of transmitting (numTx) and the number of receive (numRx) antennas respectively. In the case of multi path fading scenario, any given receive and transmit antenna, the relationship is qualified by the channel path gain vector. Hence, received signal at any time duration depends on the values of transmitted signals which are in present and obtained earlier. This introduces another parameter namely path delay represented by L. in the case of multi-path case, to compute received signals the MIMO operations are iterated for each value of path delay vector observed in flat fading.

The technical recommendations provided by 3GPP specify three models which are specific to three different types of multi-fading channel models they are extended vehicular A (EVA), Extended pedestrian A (EPA) and extended typical urban (ETU). Models like these take advantage of the channel modeling functions in LTE. The simulation is developed in Matlab by using the system object comm.MIMOChannel to understand the effects of multiple antennas along with their multiple propagation paths for implementing MIMO channel model. The system object, comm.MIMOChannel uses different parameters such as transmit and receive antennas, delay profile, Doppler shift, flat or frequency selective fading MIMO channel. The channel for multi-path fading is represented as a combination of delay profiles and maximum Doppler frequency. The overall performance is affected by spatial correlations between transmit and receive antennas in a transmission scenario involving MIMO. Since MIMO works well in multi-path fading and in environments that have maximum scattering, it is necessary to minimize the correlation found in different antenna ports, at both ends of the receiver and transmitter. In such a condition the performance is enhanced because minimizing correlations will reduce the chance of rank deficiency in Matlab.

Consider a 2 x 2 MIMO transmitter side antenna configuration. Let the enhanced node base station is represented as eNodeB. Let Mtx be the spatial correlation matrix with diagonal elements mentioned by parameter $\alpha$. Then, the spatial correlation matrix is given as,
\[
M_{tx} = \begin{bmatrix}
1 & \alpha \\
\alpha^* & 1
\end{bmatrix}
\] (3)

Let user equipment (UE) be considered as the receiver side. Let the spatial correlation matrix at UE be represented as \(M_{rx}\). If this is specified by another parameter \(\beta\) then, the spatial correlation matrix for UE at receive side is given by,

\[
M_{rx} = \begin{bmatrix}
1 & \beta \\
\beta^* & 1
\end{bmatrix}
\] (4)

According to 3GPP, the correlation matrix of spatial channel mode is:

\[
R_{spat} = R_{enb} \otimes R_{ue}
\] (5)

MIMO correlation matrix is expressed in equation as follows,

\[
R_{spat} = R_{enb} \otimes R_{ue} = \begin{bmatrix}
1 & \alpha \\
\alpha^* & 1
\end{bmatrix} \otimes \begin{bmatrix}
1 & \beta \\
\beta^* & 1
\end{bmatrix}
\] (6)

\[
= \begin{bmatrix}
1 & \beta & \alpha & \alpha \beta \\
\beta^* & 1 & \alpha \beta^* & \alpha \\
\alpha^* & \alpha^* \beta & 1 & \beta \\
\alpha^* \beta^* & \alpha^* & \beta^* & 1
\end{bmatrix}
\] (7)

In LTE specification, three levels of correlation are defined namely, low or no correlation, medium and high. The values in parameters \(\alpha\) and \(\beta\) reflect the correlation levels in the above matrix. Channel model specific to LTE is implemented using the system object \texttt{comm.LTEMIMOChannel} in Matlab. This system object takes parameters from the configuration of antenna and the values of correlation between transmitter antennas to compute all operations related to channel modeling. The channel capacity in MIMO and in multiuser MIMO depends on if the channel is static, fading and the conditions of the channel on both sides namely transmitter and receiver. The power allocation is optimal and uniform at transmitter when the channel is unknown. However this can lead to outage probability, because the transmitter will be unable to decide on the rate of transmission. In the case of fading, the knowledge of receiver or transmitter is the average of the static channel. The SNR is improved by means of beam forming techniques.

Beam forming improved SNR and signal to interference noise ratio (SINR) in multiple user scenarios and referred as linear filtering in the spatial domain. In beam forming the same symbol is sent with a different scale actor over each transmit antenna. At the receiving end, all the signals received are combined by using different scale factor. The optimizing of scale factors will maximize the SNR because beam forming produces diversity in transmitter and receiversonsystem. At spatial domain, beam forming is also interpreted as linear filtering. In beam forming, assume antenna array having
N elements receive RF signals from a certain direction. Here the underlying signal does not change, and due to the geometry of the antenna the impinging RF signal reaches the antenna elements at different times. The phases of RF signals are adjusted to achieve superposition in a constructive manner. In the desired direction the antenna pattern can be matched and the antenna pattern is shaped by the additional weighting of RF signals. The same principle can be applied to sender or transmitter. In beam forming space division multiple access (SDMA) is enabled which is an alternative to time-division (TDMA) or frequency-division multiple access (FDMA). SNR and SNIR gains are used to decrease or increase error rates when switching to a higher order modulation scheme. With beam forming in MIMO systems, there is a design tradeoff between capacity and diversity. The system object (comm.LTEMIMOCChannel) is specific to LTE channel modeling implements three channel models viz, EPA, EVA and ETU. The modeling operations are computed for all necessary channels by taking a different set of parameters to include antenna configurations and correlation level between transmit antennas.

4.1 Specifications and System Model

The LTE system model for PHY integrates various technology aspects. The model for the system includes a transmitter, channel model along with the receiver. The transmitter with various channel models for evaluating performance is specified by standards. However, standards are not followed closely by the receiver as different system designers provide unique performance profiles. The LTE down-link transceiver contains a transmitter that processes the payload bits which are provided by transport channel. The output from transmitter consists of a symbols sequence which are transmitted on the available transmits antennas. The received symbols are operated by the receiver. The different strategies made to invert operations of transmitter and receiver provides the best estimate of transmitted payload bits.

4.2 Transmitter Model and MATLAB Function

At the transmitter end the transport channel provides the payload bits on which the signal processing chain is employed. The down-link scheduler defines the processing in the transmission mode. The choice of MIMO technique is based on the transmission mode used at any given sub-frame. In the transmitter, for each sub-frame, one of the four transmission modes is selected. The transmission modes are: SIMO, transmit diversity which improves the overall link reliability, spatial multiplexing MIMO techniques to boost data rates and the closed loop spatial multiplexing which provides highest data rates in low-mobility scenarios which are achieved by the LTE standard. Each transmission mode involves many operations in a combination of processing steps namely, down-link shared channel (DLSCH) and down-link shared physical channel (PDSCH). All the transmission modes have most of the PDSCH and DLSCH operations in common. The common operations in MIMO include the attachments of cyclic redundancy check (CRC) and code-block segmentation, turbo-coding, rate-mechanism and for generating code words the usage of code-
block concatenation. The inputs for PDSCH processing include code-words because one or two code-words are supported by the LTE down-link specification. The other common operations in PDSCH will include scrambling, the generation of modulation symbols using modulation of scrambled bits, the resource elements is mapped with modulation symbols and for transmission on each antenna port OFDM signal is generated.

In MIMO operations, different transmission modes are differentiated. The modulated symbols are applied with transmit diversity and this is viewed as a combination of layer-mapping and pre-coding operations. The sub-streams meant for various transmit antennas is done by the transmit-diversity encoder which sub-divides the modulated stream. Transmit diversity is a special type of pre-coding because it assigns orthogonally transformed sub-stream to each transmit antenna. The operations of pre-coding and layer mapping on modulated symbols are done in spatial multiplexing. The resource elements for the resource grid are the outputs of MIMO operations.

For a given sub-frame in the transmission mode, the MATLAB function provides down-link transmitter operations for the LTE. In MATLAB this is viewed as the combination of SIMO, transmit-diversity, open loop, and closed loop spatial multiplexing transmitters. Let nS be the sub-frame number which is the input for the MATLAB function and uses three parameters namely,prmLTEDLSCH, prmLTEPDSCH and prmMdrl. This function when called in each sub-frame will generate payload bits for transport block which further evokes the operations that are common to DLSCH and PDSCH. The specific MIMO operations for particular transmitted mode are performed by the switch-case statement in MATLAB. The output symbols from MIMO and resource symbols for the specific cell are mapped to resource grid. The operations for transmission operations in OFDM are applied to the resource grid to finally generate output transmitted symbols represented as txSig.

4.3 Channel Model and Matlab Function

Using a combination of MIMO fading channel along with Additive White Gaussian Noise (AWGN) channel, the channel modeling is performed. The transmitted signals over the multiple antennas and the received signals at multiple antennas at receiver end are specified by relationships in MIMO channels. The parameters normally include configurations of antennas, profiles containing a multipath delay, In both the sides, Doppler shifts and spatial correlation levels amongst antennas are found, i.e., at receiver and transmitter. AWGN channel specifies the signal to noise ratio (SNR) or variance in noise.

The MATLAB function for channel model is performed by the combining MIMO fading channel with AWGN channel. The function used is MIMOFadingChan to generates the faded version of the signal transmitted represented as rxFade. This corresponds to a channel matrix (chPathG). The faded signal is computed using multiple transmit antennas in MIMO fading as a linear combination. This can result in the output signal (rxFade) to obtain average power or signal variance of one. In order to compute variance in noise, required to carry out AWGNCchannel function, the signal variance (sigPow) is computed first. The variance for noise is derived as the difference of signal power and SNR value in dB.
4.4 Receiver Model and MATLAB function

In the receiver model, the received symbols are applied with signal processing and this is followed by channel modeling. The operations at the receiver are not dependent on the mode of transmission. The receiver operations include the receiver for OFDM, resource element de-mapping and cell specific reference (CSR) signal extraction. The CSR signal which is received is used to determine the channel response matrices in each sub-frame. The MATLAB function takes the sub-frame number nS as input and the channel rxSig processes the OFDM signal. The process also estimates the noise variance (nVar) for each received channel, the matrices for path gain of the channel (chPathG), and transmitted cell specific reference signals (csr_ref). The three parameters namely prmLTEDLSCH, prmLTEPDSCH and prmMdl are also used in the receiver model. The function generates the output at the best estimates of the transport block payload bits. The output signal is computed by performing de-modulation, channel decoding, de-scrambling and CRC-detection operations.

4.5 Simulation with MATLAB

MATLAB is used in this project for simulations. The different LTE functions are used while executing the code. Numerical outputs are generated at each stage. MATLAB Simulink simplifies the translation from specification to a final blueprint for implementation. The MATLAB software introduces proprietary algorithms and allows performance evaluations at the system level. Simulation of large data sets is possible and also the gaps in implementation can be addressed. LTE algorithm and system design are easily available in MATLAB communications toolbox, the simulations can be accelerated in a variety of options in MATLAB. C or C++ code generation is possible with MATLAB and verifications can be done with hardware in the loop. The system overview of simulation is illustrated in figure 8.
The down-link communication from an E-UTRAN NodeB (eNodeB) to one user equipment (UE) using the fading channel (AWGN) is simulated. The simulator is made up of four main parts namely the transmitter (eNodeB), channel, receiver (UE) and the outputs to show the performance under the conditions:

1. Channel response for MIMO and SISO
2. LTE performance with MIMO under Rayleigh fading channel
3. LTE performance with MIMO under Rician fading channel
4. Throughput under Rayleigh fading channel
5. Throughput under Rician fading channel

The simulator is modeled in the physical layer and also in the medium access control (MAC) layer partly. The simulator will focus on PDSCH in terms of the physical channel. The operations in the simulator are done in terms of sub-frames as the transmission of signals is in the form of sub-frames. The outputs are provided in the following results section.

5 RESULTS AND DISCUSSIONS

In this chapter the results obtained from simulations is discussed. The simulations are done taking 2x2 receiver and transmitter antenna configuration.

Channel capacity to an additive white gaussian noise (AWGN) channel with BH bandwidth and signal to noise ratio S/N according to Shannon-Hartley theorem is

\[ C = B \log_2(1 + S/N) \]  
(8)
\[ C_{\text{AWGN}} = N \log_2 (1 + \frac{\bar{P}}{N_0.W}) \ \text{[bits/S]} \] (9)

where \( \bar{P}/(N_0.W) \) is the received signal to noise ratio (SNR). The channel capacity of SISO and MIMO obtained from simulation is shown in figure 9 using these equations 8 and 9.

Figure 9: Graph of channel capacity

SISO systems are the simplest form of communication systems as they employ SISO communication systems which use only one antenna at the sending and receiving station. In the case of MIMO, the signal between the receiver and transmitter can go through multiple paths and antennas and the path of the signal can change if UE moves along a distance. From the graph in figure 9, the capacity is increasing as the antenna number increases for transmit and receive locations. The blue line shows the SISO system and the red line denotes MIMO performance which shows increased capacity. The capacity of MIMO is found to be better compared to SISO and found to increase with higher values of SNR which is not preferred in wireless transmission.

Simulations were performed to understand the performance of LTE up-link transmission with MIMO in Rayleigh fading channel. The throughput against SNR in Rayleigh fading channel is also simulated. In the transmitter side, data bits are generated and CRC bits are calculated and added. The output information is segmented to code blocks by the one-third rate of turbo coder and this is followed by adapting the rate matching process for a suitable code rate. In the LTE transmitter, operations are performed to generate up to two different streams or code-word. This provides good performance in terms of peak data rates along with corresponding spectral efficiencies, capacity and QoS management, but can lead to complexities in the network.

At the receiver, the signal is processed with inverse order of blocks in comparison with the transmitter. The LTE receiver design can estimate the channel and signal detection. The signal is decoded and CRC is computed, and if the signal is found to be correct, an acknowledgement is sent to the transmitter and the bit error rate (BER) and throughput are calculated. The channel estimation
function will measure the reference symbols and compare them with the corresponding transmitted signal. This is followed by estimation of phase shift, which is removed and the information bits are recovered. Fading is a characteristic of radio signals. In this simulation Rayleigh channel fading is used to show the performance of LTE advanced system. Rayleigh channel is normally used in narrowband wireless and in mobile cellular communications. The simulation is done by generating data in a given channel quality indicator (CQI), signal to noise ratio (SNR) with many sub-frames. The channel quality indicator provides information related to modulation order and effective code rate (ECR) which are then transmitted over the radio channel. At the receiver the channel estimation and signal detection is done to retrieve the originally transmitted channel. The equations for BER and SNR are stated below.

\[
BER = \frac{\text{error bits}}{\text{number of transmitted bits}}
\]  

\[
SNR = \frac{E_b}{N_o}
\]  

\[
BER \propto \frac{1}{SNR}
\]  

\[
E_s/N_o = K.E_b/N_o
\]

where, \(E_b\) = bit energy, \(E_s\) = Symbol energy, \(N_o\) = Noise power spectral density, \(K\) = Number of bits per second. The simulation result is shown for BER and SNR in a fading channel, in figure 10. The graph in figure 10, shows the BER for different SNR and CQI values. The red curve shows the LTE performance under SISO and blue denotes MIMO. The curve provides the performance of LTE advanced system in combination of the techniques namely, channel estimation and signal detection. Figure 10 which shows the LTE performance of with MIMO in Rayleigh fading is calculated with equations 10 and 11.

![Figure 10: LTE performance with MIMO in Rayleigh fading channel](image-url)
The throughput performance in Rayleigh fading channel is shown in figure 11.

![Throughput under Rayleigh Fading Channel](image)

**Figure 11:** LTE performance with MIMO in Rayleigh fading channel

The throughput performance graph is generated with function as SNR. The green curve denotes the BER performance to depict LTE up-link. It can be found that the throughput increases with SNR. This performance is found to be better compared to SISO. The results show superior performance with 2x2 MIMO LTE systems over SISO LTE configuration. It is important to note that the performance depends on the techniques of channel estimation and signal detection.

Likewise, simulations for LTE throughput performance was done using the Rician fading channel. The BER analysis of MIMO system was done for different values of CQI and SNR. Figure 12 shows the result of LTE performance with the Rician fading channel.
From graph in figure 12 it can be found that BER is found to decrease with an increasing number of antennas. Due to the spatial diversity in MIMO the simulation result shown here denotes better BER performance in comparison to SISO antenna configuration. The throughput performance in Rician fading channel is shown in figure 14.

In figure 13, LTE performance with MIMO provides satisfactory throughput performance which is found to increase when SNR values increase. The BER performance compared with SISO and
MIMO shows that MIMO improves the LTE system performance for different BER values. The LTE system under both fading channels, viz Rayleigh and Rician (figures 11, figure 12) shows that the throughput in Rician fading channel is found to be better than Rayleigh fading channel.

The simulation results presented were done for 2x2 antenna configurations for both SISO and MIMO to estimate the performance of LTE with MIMO. Results were presented to channel response, LTE performance and throughput performance under Rayleigh and Rician fading channels separately through the graphs.

6 Conclusion

LTE with MIMO due to its enhanced data throughput is gaining widespread deployment with mobile communication providers. In this report the LTE systems with MIMO is examined. MIMO systems in their transmission we make use of multiple antennas to transmit and receive signals based on same frequency. Wireless networks already use MIMO, but this is a new feature in commercial wireless networks. The project investigates the throughput capacity of LTE down-links in both spatial multiplexing and transmission diversity mode. LTE which is the 4G wireless communication is taken as a reference frame. The LTE frame is analyzed for its performance downgrade in different conditions. The simulations are done using MATLAB. The design and simulation of the OFDM system are done with cyclic prefix. The verification of Bit Error Rate (BER) is done by changing the value of Signal to Noise Ratio (SNR). The technique discussed in this project offers two vital aspects, Spatial Multiplexing (SM) and Transmit Diversity (TD). The aspects of SM and TD are examined for their effects in the throughput of the system. The project also discusses the effects of different parameters such as, mobile station speed, the number of Multi-paths, Rician factor (K) for the throughput of LTE with MIMO.

The section on literature review provides a review of the different research found in this area of LTE with MIMO from secondary sources. The section on theoretical foundations presents the theory in LTE with MIMO for the techniques such as physical signals and channels in LTE namely, transmit and receive diversity in MIMO along with spatial multiplexing. The feature of MIMO is a standard in next generation networks and plays a significant role in improved data rates and this includes system capacity in cellular network services. In spite of its advantages, the network operates face challenges with MIMO. Cellular networks traditionally provide services under line-of-sight (LOS) conditions. MIMO is found to work under conditions that have rich scattering (signals bounce around the environment). Wireless service providers must have their networks optimized in order to achieve throughputs in LTE systems that target multipath rich scattering conditions for MIMO. Along with multipath conditions, signal to noise ratio (SNR) must be high for each multipath signal. MATLAB simulations are performed to understand LTE performance with MIMO.

LTE along with MIMO plays a significant role in next generation wireless networks. LTE along with MIMO fulfills the growing demands in throughput and system robustness for the user. The
simulations in MATLAB included cyclic prefix is used in the design and simulation of OFDM system. The verification of Bit Error Rate (BER) is done for different Signal to Noise Ratio (SNR) values. OFDM system is investigated eliminating the cyclic prefix. It can be seen that in the configuration of MIMO, it consists of two antennas which are used receive multiple data streams via different spatial paths. This implies the same frequency is spread out in time for transmitting data streams. The concept of beam forming may be utilized by MIMO systems. MIMO technologies when used in LTE provide better down-link peak rate, cells coverage and improved average cells throughput. LTE offers increased capacity while using standard antenna technique to provide vital aspects namely spatial multiplexing and transmit diversity. These two aspects are examined for their effect on throughput in the system. In this project the effect of parameters namely, the speed of mobile station, the number of Multipath, Rician factor (K) on the throughput of such systems is discussed and reported. The report evaluates the performance of LTE using MIMO in order to explain LTE system capacity, average cell throughput of LTE at different bandwidths and BER performance against SNR. Simulations were done separately for channel response, performance and throughput under Rayleigh fading and Rician fading channels respectively. The graphs for the simulations are presented for 2 x 2 antenna configurations for both SISO and MIMO to show BER against SNR. In different simulation scenarios it was found that the performance of LTE with MIMO is found to be better compared to SISO. The simulation provided the insight that in order to derive good LTE performance, an optimized MIMO system will provide substantial throughput gains without additional expenses in adding spectrum because MIMO is a more widely deployed antenna technique.

REFERENCES


