Multi-User Detection (MUD) Scheme for Mitigating Co-Channel-Interference in Heterogeneous 5G Networks

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ABSTRACT

It could be stated that to satisfy the ever-increasing capacity of LTE networks in terms of number of User Equipment (UE) and volume of traffic, Small-Cell architecture seems to be a competitive candidate. However, such systems will be Co Channel Interference (CCI) limited since densification of Base Stations (BS) will enforce reuse of the same frequencies in neighboring geographical regions, resulting in unacceptable levels of CCI. Previous researches has shown that, despite the higher signal power level available due to the reduced cell sizes, Single User Detection (SUD) techniques are still unable to sustain the required performance as a result of low Signal to Noise Interference Ratios of concern. Multi-User Detection (MUD) mechanisms are shown to be a promising solution to yield higher system capacity and acceptable levels of performance where multiple users communicate in the system simultaneously.

The main aim of the current study is to highlight a MUD solution for mitigating the unacceptably high levels of CCI in Small Cell networks using the current spectrum allocated for the International Mobile Telecommunications (IMT) services by International Telecommunications Union (ITU). In addition, the proposed work focuses on OFDM framework where the existing Single-User system is extended to Multi-User one in order to improve system performance. Results have clearly depicted this improvement in system performance by the proposed MUD.

Keywords: IMT-2020 Systems, 5G, Multi User Systems, Multi User Detection, Small-Cell, Co-Channel-Interference, Massive MIMO, Channel State Information.

ÖZ

Günümüzde 4G ağlarının sürekli artan kullanıcı sayısı ve trafik hacmi kapasitesini karşılamak için, “Küçük Hücre Mimarisi” yaygın olarak kullanılmaya başlamıştır. Bu sistemlerde baz istasyonlarının yoğunlaştırılması ile komşu coğrafi bölgelerde aynı frekansların yeniden kullanımını gerektirmesi, kullanıcıların iletişimini olumsuz etkileyecek seviyelerde komşu hücre paraziti oluşumuna neden olmaktadır. Önceki araştırmalar, azaltılmış hücre boyutları nedeniyle ortaya çıkan yüksek sinyal gücü seviyesine rağmen “Tekli Kullanıcı Algılama” tekniklerinin düşük “Sinyal-Gürültü-Parazit Oranları” nedeniyle gerekli performansı sürdüremediğini göstermiştir. Bu anlamda “Çoklu Kullanıcı Algılama” tekniklerinin birçok kullanıcıya aynı anda, daha yüksek sistem kapasitesi ve kabul edilebilir performans sağlanması için ümit vaat eden bir çözüm olduğu görülmektedir.

Bu çalışmada, 4G için tahsis edilen mevcut spektrum kullanılarak, küçük hücre ağlarındaki kabul edilemez derecede yüksek parazit seviyelerini hafifletmek için bir "Çoklu Kullanıcı Algılama" çözümü sunulmuştur. Ayrıca, çalışmada tek kullanıcılı OFDM sistemi ve tek kullanıcılı sistemin genişletildiği çoklu kullanıcı sistemleri incelenmiş olup, iki sistem arasındaki farklılıklar ortaya konmuştur. Çalışma sonucunda elde edilen sonuçlar, önerilen "Çoklu Kullanıcı Algılama" sistemi performansında anlamlı bir iyileşme göstermiştir.

Anahtar Kelimeler: IMT-2020 Sistemler, 5G, Çoklu Kullanıcı Sistemleri, Çoklu Kullanıcı Algılama, Küçük Hücre Mimarisi, Komşu Hücre Paraziti, MIMO, Kanal Bilgisi.

DEDICATION

To my father Altay, my mother Şerife, my sister Mine Ramazan
and my love Eda Karasaç

For their love, supports and encouragements.

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I would like to gratefully acknowledge the people who have helped me through my thesis including my magnificent supervisors and my lovely family members. First, I would like to thank my supervisor Prof. Dr. Hasan Amca for his outstanding effort and support. The last but not least, I want to express my heartfelt gratitude to my family members for their encouragements and their unconditional love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

$\mathbb{C}$	Complex Number
$\sim \mathcal{CN}(0,1)$	Zero mean and Unit variance
U_i	Resource Block assigned by *i*-th eNodeB
U	Total number of Resource-Blocks
B	Number of eNodeB
N_{Tx}	Number of transmit antenna
N_{Rx}	Number of receive antenna
$\mathbf{X}_i$	Transmitted signal derived from *i*-th eNodeB
$\boldsymbol{Y}_{ik}$	Received signal by *k*-th UE derived from *i*-th eNodeB
$\mathbf{H}_{ik}$	Channel coefficients between *i*-th eNodeB and *k*-th UE
$\mathbf{H}_k^{i*}$	Conjugate of channel coefficients *i*-th eNodeB and *k*-th UE
$\mathbf{H}_{\text{eff}}^i$	Effective CSI for *i*-th eNodeB
$\mathbf{Z}_k$	Additive White Gaussian Noise at *k*-th UE
$\mathbf{Z}_{k,\text{I}}$	Co Channel Interference at the *k*-th UE due to *I*-th eNodeB
$\widetilde{\boldsymbol{H}}_{ik}$	Cooperatively estimated CSI between *i*-th eNodeB and *k*-th UE
$\widetilde{\boldsymbol{Y}}_{ik}$	Estimated receive signal at the *k*-th UE due to *I*-th eNodeB
$\mathbf{W}_i$	Complex conjugate of *i*-th eNodeB channel coefficients
$\mathbf{V}_{ik}$	Zero Forcing signal output at *k*-th UE drived by *i*-th eNodeB
$[\ \cdots\ ]^T$	Transpoze of a Matrix
$(\mathbf{H}_{\text{eff}}^i)^{\text{H}}$	Hermitation Transpoze of Effective CSI for *i*-th eNodeB
$\boldsymbol{c}_k$	Coded signal for *k*-th UE
$\boldsymbol{\Pi}_k$	Interleaved signal for *k*-th UE

N_{fft}	Number of Fast Fourier Transform
T_g	Amount of Guard time
$\mathbf{x}_k$	Transmit signal of *k*-th UE
$\tilde{\mathbf{x}}_k$	Estimated transmit signal for *k*-th UE
$\boldsymbol{y}_k$	Receive signal of *k*-th UE
$\mathbf{H}_k$	Channel coefficients of *k*-th UE
K	Number of total users in the system
N	Number of active users
P_s	Number of bytes in each frame
F_s	Number of packets in each frame
N_{ps}	Number of bit in each byte
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
AWGN	Additive White Gaussian Noise
BC	Broadcast Channel
BD	Block Diagonalization
BER	Bit Error Rate
CCI	Co Channel Interference
CDMA	Code Division Multiple Access
CI	Channel Inversion
CP	Cyclic Prefix
CPU	Central Processing Unit
CSI	Channel State Information
D2D	Device to Device

DFE	Decision Feedback Equalizer
DL	Downlink
eNodeB	Evolved Node B
FFT	Fast Fourier Transform
GFDM	Generalized Frequency Division Multiplexing
HetNet	Heterogeneous Network
ICI	Inter Cell Interference
IFFT	Inverse Fast Fourier Transform
IMT	International Mobile Communication
IoT	Internet of Things
ISI	Inter Symbol Interference
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union Radiocommunication
IUI	Inter User Interference
Lab-VIEW	Laboratory Virtual Instrument Engineering Workbench
LS	Least Squares
LTE	Long Term Evaluation
LTE-A	Long Term Evaluation Advanced
MaC	Macro Cell
MAC	Multiple Access Channel
MATLAB	Matrix Laboratory
MDC	Multiple Descriptions Coding
MIMO	Multiple Input Multiple Output
MMSE	Minimum Mean Square Error
MRC	Maximal Ratio Combining

MUD	Multi-User Detection
N-IFFT	Number of Inverse Fast Fourier Transform
OFDM	Orthogonal Frequency Division Multiplexing
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAN	Radio Access Network
RB	Resource Block
RCI	Regularized Channel Inversion
RE	Resource Element
SISO	Single Input Single Output
SmC	Small Cell
SNIR	Signal to Noise Interference Ratios
SNR	Signal to Noise Ratio
SUD	Single-User Detection
TDMA	Time Division Multiple Access
UE	User Equipment
UL	Uplink
USRP	Universal Software Radio Peripheral
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
ZF	Zero Forcing

Chapter 1

INTRODUCTION

1.1 Problem Statement

It could be stressed that recent developments in mobile industry have changed drastically as number of smart devices such as smart phones, tablets, laptops, Device to Device (D2D) machines/sensors/actuators and Internet of Things (IoT) devices are exponentially increased. Currently, network operators are not face with the coverage; the subject that they have been interested is the capacity [15]. Furthermore, data demand from many applications such as YouTube, Facebook, Instagram, Google Maps has also been substantially rose [9].

By year 2020, Cisco is offering monthly volume of mobile data traffic will increase by 10 times of its value in year 2014 and will increase by 25 times which implicitly means that data traffic will be almost doubled per month. Similarly, a report published by Ericson in year 2015 shows that, number of devices are expected to reach 26 billion in 2020 [7]. In addition to these, International Mobile Communication 2020 (IMT-2020) Promotion Group which defined by International Telecommunication Union Radiocommunication (ITU-R) sector appointed some standards such as an increase in capacity by thousand times as well as an increase on efficiency of power by more than hundred times and lastly a declining cost by more than hundred times. Besides of these, IMT-2020 also foresees bandwidth efficiency to increase by 3-5 times, data rate for a user will be among 0.1-1 Gbps. Moreover, end to end delays on network will decline from >30ms to <5ms [15, 17 and 18]. Detailed information about IMT-2020 and expectations of it will be mentioned in Chapter 2.

Aside from the mentioned improvements it could be signified that the connection density will enable a million connections per square kilometer, mobility will be more than 500-km per hour and the optimum rate of data will be tens of Gbps [16]. To deliver these promises, the whole communications topology and network mechanism should be upgraded.

It could be lamented that increase in the usage of smart personal communication and IoT devices generated the requirement of denser base station network to boost capacity. Furthermore, placing Base Stations (BSs) in a more congested manner which referred as "*Heterogeneous Network*", particularly at malls, management offices, schools, hotels to fulfil the users' data demands may lead in overlapping coverage areas as well as severe inter-cell and intra-cell interference among the communicating devices of the users [9, 15]. The more establishing Small Cell (SmC) architecture could be one of the best alternatives to cope with growing data demands of the User Equipment (UE) on Heterogeneous Network (HetNet) in forms of and volume of traffic [1, 15]. Within a HetNet, Macro Cells (MaCs) and Small Cells (SmCs) use the same frequency; since the reuse of same radio frequency spectrum can help to increase network capacity thus reach the peak data rate. Extensive more information related with HetNet also presented in Chapter 2.

However, in such frameworks every user may face with Co Channel Interference (CCI) due to the densification of BS which may cause the reuse of the same frequencies in neighboring. It could be mentioned that CCI will negatively influences wave signals which in turn yields an undesirable bit errors which then reduce the speed of data transmissions among BS and UE. It is also discussed that disconnection during handover is one of the key ingredients of negative impact of CCI.

In addition to these, it could be mentioned that the Multiple Input Multiple Output (MIMO) system provides the use of diversity gain and spatial multiplexing, thus gives an opportunity to increase data rate for such systems [8]. Most of currently used Multiple Input Multiple Output – Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems are based on Single User Detection (SUD) framework where CSI is restricted by the Signal to Noise Ratio (SNR) due to existing CCI.

Despite the MIMO technology and the availability of higher signal power level as a result of reduced cell sizes, SUD techniques are not eligible to fulfil the required achievable level of performance as low Signal to Noise Interference Ratios (SNIR) existing. To struggle with challenges, Multi-User Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MU-MIMO-OFDM) technology is promising solution to eliminate fading and mitigate undesired CCI. Wireless communication systems in MIMO-OFDM technology need to serve in forms of multiple user equipment who are sharing the same radio resources simultaneously to avoid unacceptable level of CCI to achieve required capacity [10]. Therefore, MU-MIMO mechanisms are required to yield higher system capacity, spectral efficiency and acceptable levels of performance in HetNet.

There are several curiously asked questions; “What is the minimum Bit Error Rate (BER) for multi-user system for achieving high data rate?” and more important

“How can it possible to achieve simultaneously for multiple user?”. Precisely at this point proposed study provides efficient BER multiuser detection method for avoiding inter-cell and intra-cell interference to serve multiple user simultaneously with using Orthogonal Frequency Division Multiplexing (OFDM) system.

1.2 Literature Review

The scholarly research [1] tested the cooperative interference mitigation by employing Small Cell (SmC) in interfering heterogeneous Long Term Evaluation (LTE) networks, mainly for the user equipment at the cell edges. A practical low complexity cooperative interference mitigation algorithm is applied to hinder the CCI. Therefore, resulting performance can be expressed as almost-optimum.

A study which conducted in a similar field, aimed to explore the impact of Small Cell – Macro Cell (SmC-MaC) cooperation is assigned to improve data rate and reliability of uplink transmission in heterogeneous networks by administering SUD approach for a two-user through using Macro Cell - Base Station (MaC-BS) and a Small Cell - Base Station (SmC-BS) [2]. The main focus of the proposed technique is to concentrate on MaC to SmC quantized feedback and relaying from SmC to MaC and cooperative spectrum allocation between SmC and MaC. The researchers also introduced transmission scheme which primarily relies on superposition block Markov encoding at the device of users. It could be signaled that there is a proportional relationship among MaC quantization and spectral efficiency. To be more precise, optimal MaC quantization would generate maximum spectral efficiency. Outage probability over block fading channels is also formulated for channel variations over different blocks.

Rahman, Sacchi and Schlegel proposed in [3] a cooperative multi-point transmission scheme for Long Term Evaluation Advanced (LTE-A) uplink at the Evolved NodeB (eNodeB) level in order to improve system diversity without increasing terminal complexity. The impact of channel estimation and channel coding on link performance is also analyzed for various Generation Partnership Project (3GPP) standards. Link energy efficiency analysis also showed the dramatic performance improvement by cooperative transmission techniques for Long Term Evaluation - Advanced (LTE-Advanced) in uplink direction where imperfect channel estimation represents a critical issue of impairing eNodeBs coordination even with robust channel coding.

The research which conducted by Chen, Chen and Lin in [4] combined the benefits of Multiple Descriptions Coding (MDC) and multipath routing to obtain the best video quality in spite of the packet losses when roaming. The channel status detection mechanism has been incorporated to decide which channels will be selected to get the advantage of path diversity for delivering streaming video. The stimulation results demonstrated a significant improvement in the quality of streamed video during roaming in Wireless Local Area Network (WLAN) environments.

A coordinated multipoint heterogeneous wireless cellular communication system employing large number of jointly transmitting BSs to mitigate Inter Cell Interference (ICI) and improve coverage and spectral efficiency has been presented in a [5]. The study also provides an expression governing coverage probability for a User Equipment (UE) equidistant from three base stations. The results which illustrated for the 2 cooperating BS case show that for typical user equipment at a location are more likely to generate moderate performance, there is a 17%

improvement while the user equipment situated at a position that creates worst performance resulted in a 25% improvement when compared with the non-cooperative base stations case. The research also recommended that no diversity gain is acquired when noncoherent joint transmission is appointed, and full diversity gain is obtained when base stations are employing coherent joint transmission by executing the Channel State Information (CSI).

Moreover, article [6] proposes a system-wide load balancing scheme for multi-domain cooperative WLAN, Wireless Fidelity (Wi-Fi), Bluetooth terminals are operating in an interference limited environment where the network state information is picked from different WLANs is practiced in adaptively to neglect the Co Channel Interference and optimizing resource utilization. The presented optimization process also considers the impact of the all other interfering sources in the operating environment. Simulation results revealed that the proposed multi-domain load balancing scheme as a complement to the interference mitigation mechanism outperforms the schemes which do not consider inter-domain or environmental interference [8].

As previously indicated one of the focal points of the study is to outline Multi-User MIMO-OFDM as it is one of the key pre-requisites to eliminate undesired co-channel interference for obtaining optimum speed by considering bit error performance. Therefore, first the terminology of multiuser should be clearly described with the light of the previous studies.

Enthusiasm for the investigation of multiuser MIMO-OFDM frameworks has expanded, particularly the improvement of Multi-User Detection (MUD) methods in such frameworks consist of Zero Forcing (ZF) detection, Minimum Mean Square Error (MMSE) identification method, Hybrid, Decision Feedback Equalizer (DFE) detection and more different detection approaches. The conducted study [11] focused more with linear pre-coding methods for each user to overcome with the existing CCI with Block Diagonalization (BD) technique and Channel Inversion (CI) method. The study has also discussed hardware implementation with Universal Software Radio Peripheral (USRP) hardware and Laboratory Virtual Instrument Engineering Workbench (LabVIEW) Software in a real world multiple user MIMO propagation environment. The results showed that the spectral efficiency and capacity of the system significantly increased. Apart from these, Signal to Noise Ratio (SNR) values were almost-optimum and different modulation techniques were not evaluated. Furthermore, study also outlined that in some cases that CSI were malfunctioning simultaneously to communicate in Multi-User (MU) system.

Aside from these, various studies had been conducted to mention how to reduce effect of inter user interference. For instance, one research had discussed that Regularized Channel Inversion (RCI) which based on MMSE by employing Generalized Frequency Division Multiplexing (GFDM) among different number of users and study provides an opportunity to observe the differences between OFDM and GFDM. In addition to all these, the study also stressed that OFDM and GFDM gives similar performance for multiuser case. Besides of these, results of the simulation also signified that as number of users increases, CCI interference will raise dramatically in MU-MIMO-GFDM with RCI [12]. To create better understanding, the seatbacks of the above-mentioned study could be indicated as; RCI method did not mentioned execution of MU-MIMO on OFDM system and only considered for 16 - Quadrature Amplitude Modulation (16-QAM) modulation technique and drawn a discussion in MU-MIMO-GFDM.

Unlike a Linear Pro Coding (LP) method, Non Linear Pre Coding (NLP) represented in [13] for downlink MU-MIMO in flat Rayleigh fading channel. Tomlinson Harashima Pre Coding (THP) approach is implemented through successive pre-cancellation to hinder the undesired Inter User Interference (IUI) among different users. Non-linear systems enabling higher data transmission speed when compared with linear systems. However, NLP systems are more likely to require higher hardware complexity.

However, presented intense of research results have shown that increasing of the number of users in Multi-User systems cause a critical increasing in bit error rate performance. System performance must be stable against multiuser communication.

1.3 Significance of the Study

Previous researches have shown that, Single-User Detection (SUD) techniques are still unable to sustain the required performance due to the low SNR of concern and spectral efficiency as well as capacity. Multi-User MIMO-OFDM system provides an opportunity to reach to maximum capacity within existing channel simultaneously among the active multiple users within the system.

One of the key challenges in designing multiuser communications systems could be stressed as mitigating interference. Through multi user channel estimation and detection scheme, the detrimental effects of the CCI on these spectrally overlapping systems could be eliminated thus provides a great chance to improve capacity, system performance as well as diversity [8]. The main principle of Multi-User systems is providing multiple independent parallel streams unlike traditionally used Single-User detectors. Advanced signal detection mechanisms are needed to detect simultaneously transmitted parallel streams. It can be stated that conventionally utilized SUDs are insufficient to sustain a satisfactory performance in multiuser environments.

In cellular wireless communication, Multiple Access Channel (MAC) in the uplink (UL) direction and the Broadcast-Channel (BC) in downlink (DL) direction are the two basic MIMO-OFDM transmission channels [14]. At UL transmission stage, the transmitted signal which served from the BS can be detected by different UE through using array processing. For the case of DL, BS is equipped with multiple antennas which can communicate with the single or multiple equipped antennas at the UE. The main challenge in DL case is related with Multi-User MIMO. To be more precise, BS needs to know CSI accurately which received from the UE to provide benefits which presented by MU-MIMO. The CSI is extremely useful to detect the channel knowledge by relying on the channel conditions and optimize it during the communication which is crucial for increasing channel capacity and improve error performance in single and multi-user system. Moreover, CSI takes an important role to estimate and detect real channel for each user. In MU communication systems, channel knowledge is used in matrix form for all users to eliminate all Co Channel Interference simultaneously.

The current study proposes a multi-user resource detection algorithm for cellular OFDM systems to exploit the system diversities such as frequency channel diversity, multiuser diversity and inter-cell and intra-cell diversity. The objective is to make efficient use of the resource availability so that the overall spectral efficiency is maximized while each user’s Quality of Service (QoS) requirements, including BER and data rate, are guaranteed.

The proposed Multi-User detector has been implemented on existing Single-User OFDM system by a simulator developed using Matrix Laboratory (MATLAB) program and their achievable BER versus SNR performance is evaluated with employing Channel Inversion (CI) technique. CI can be addressed as Zero Forcing (ZF) method existing in some SU systems for detection of the individual users’ data.

In MU systems, CI technique is employed to detect all parallel transmitted signals simultaneously. Meanwhile it could be stated that “*simultaneously*” means that all users share the same bandwidth at same time to support higher spectral efficiency. In this thesis, Multi-User meteorology and detection method have been employed on Single-User LTE-A program. While doing this, existing Single-User program have been shaped accordingly the multiuser scenario where multiple data generated independently and employed multiple data detection algorithm applied. In addition to these, different alternatives such as Multi-User with SUD and Multi-User with MUD based system performances in terms of BER versus SNR are compared with Single-User SUD benchmark. Further, different numbers of users are selected out of the number of users' requests who apply to communicate in the multiuser environment for better communication. This selection has been provided by using CSI feedback of each user. Scenarios with different number of users are provided to observe the differences in the forms of error probability for each user [14]. The performance results in proposed MUD mechanism in this thesis are shown to be a favorable solution to yield higher system capacity and satisfactory levels of performance in multiuser system which will be studied in Chapter 3 as well.

1.4 Organization of the Thesis

The current study is organized as follows: Introduction is presented in Chapter 1. Chapter 2 will outline the expectations towards IMT-2020, channel modeling and propagation characteristic, framework of Heterogeneous system and OFDM system as well as models employed both for single users and multi users. Chapter 3 will provide to observe parameters of developed work in this thesis as well as performance estimation results will be illustrated in terms of BER versus SNR for each three scenarios where SU-SUD, MU-SUD and MU-MUD. Finally, Chapter 4 will mention the conclusion and advices to the future related studies. Moreover, Chapter 4 will address the promises of future IMT-2020 system with MUD.

Chapter 2

THE SYSTEM MODEL

The main aim of this chapter is to portray expectations regarding IMT-2020 framework to create better understanding towards to the concepts of Single and Multi-User systems. Therefore, chapter begins with IMT-2020 framework to present preliminary information. Then channel modeling will be mentioned. More importantly, this chapter also aims to advance our understanding towards the conceptual frameworks regarding Single-User IMT System, transmitted signal model and detector for Single-User framework, Multi-User IMT System, transmitted signal model and detector for Multi-User framework respectively.

2.1 IMT-2020 Framework

2.1.1 Expectations towards IMT-2020

The main objective of this part of the study is to present information about "How did IMT start", "How the standards for Third Generation (3G), Fourth Generation (4G) or Fifth Generation (5G) technologies are determined by IMT" and the bodies who regulate and deploy IMT specifications.

ITU's IMT standards are mainly shaped by the demands on worldwide mobile conversations since 1990's. International Mobile Telecommunications or shortly IMT could be descried as a term to determine cellular structures in world. ITU membership enables studies to define the spectrum allocations as well as approve the probability of its compatibility to generate criterion for executing technologies of

IMT such as 3G, 4G and 5G. ITU formed the characteristics for IMT-2000 and first 3G deployments which proposed in 2000. It could be mentioned that in mid-2012 ITU introduced IMT-Advanced model that could be named as 4G which become common across the world. Nowadays, it could be signaled that IMT-2020 is putting intensive effort to clarify necessary specifications which required for 5G mobile cellular technologies [17, 18].

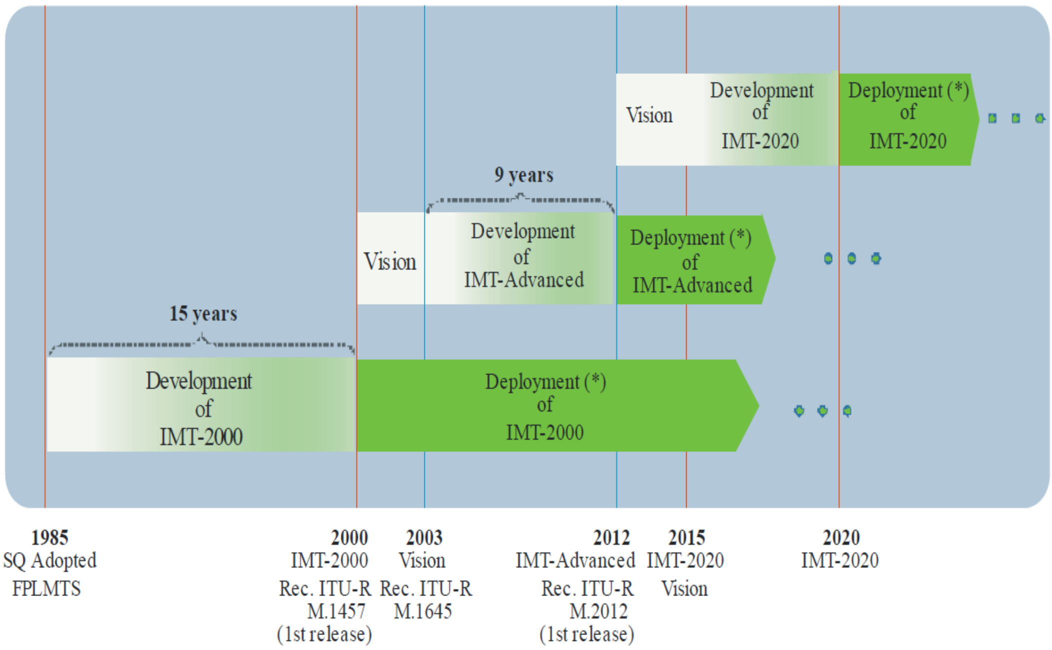

Figure 2.1: IMT Standard Evolution towards 5G [17].

Figure 2.1 illustrates the key milestones of the IMT workshops and standards. It could be lamented that to satisfy the demands towards the wireless communication in forms increased number of users, higher data rates and brand-new video or gaming services will necessitate high Quality of Service (QoS). Therefore, IMT should work hard to match the user demands. Moreover, it could be addressed that user demands are one of the vital factors which directs progress of the IMT for the upcoming years.

In addition to these, it could be expressed that new demands such as increased volume of traffic, variety of smart devices which supported by diversified service requirement will boost the quality of service which provided to users as well as lower the costs with the help of the creative, dynamic and innovative solutions. Furthermore, support of IMT-2020 to low and high mobility applications as well as wide range of data rates are shaped by considering users and their service demands in multiple user environment [7, 16, 17, 18].

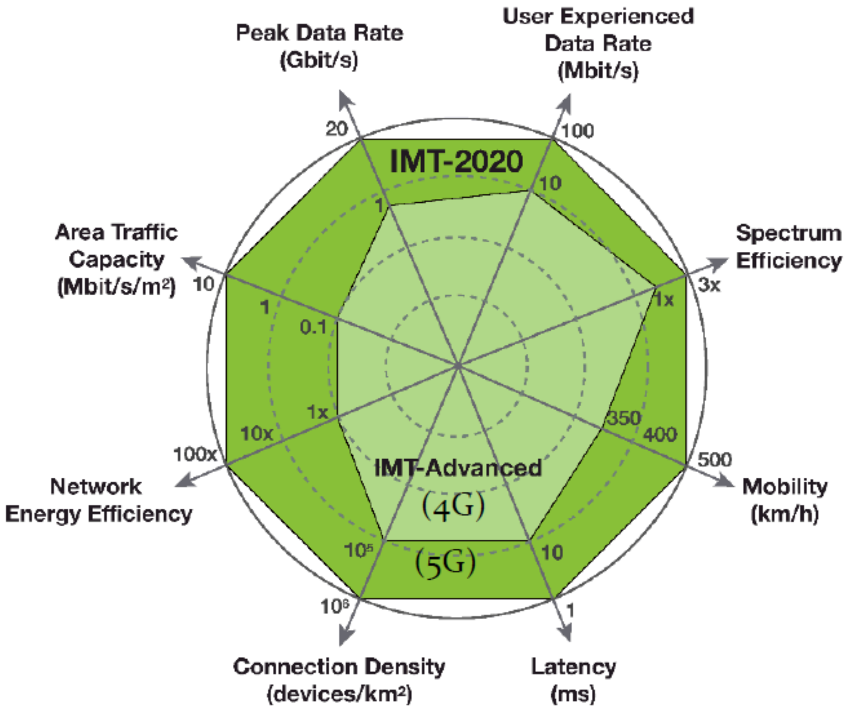

Figure 2.2: The Key Capability Expectations of 5G Compared to 4G [18].

Figure 2.2 exhibits the key capabilities of IMT-2020 (5G) by comparing the capabilities of IMT-Advanced (4G) and shortly mentions that IMT-2020 systems could be identified as mobile systems with advanced technology of LTE-Advanced mode.

As illustrated on Figure 2.2, new capabilities particularly on eight criterions which are presented by IMT-2020 group of research in [17, 18] could be listed and summarized as follows:

- **User experienced data rate:** Stands for the achievable data rate which is available at different locations within the coverage area for a UE user/device (in Mbit/s or Gbit/s).
- **Peak data rate**: Refers to optimum data rate for each user/ device (in Gbit/s).
- **Area traffic capacity**: Could be briefly identified as an overall communication traffic throughput which particularly served per geographic area (in Mbit/s/m2).
- **Energy efficiency**: In general terms, it could be expressed that energy efficiency has two aspects; (a) on the network side and (b) on the device side respectively. It could be mentioned that on the network side dimension; energy efficiency can be simply defined as quantity of information bits that are transmitted to/received from users which are communicating with BS per unit of energy consumption of the Radio Access Network (RAN) (in bit/Joule); – on the device side, energy efficiency refers to quantity of information bits per unit of energy consumption of the communication module (in bit/Joule).
- **Connection density**: Represents the total number mobile station that are connected and/or total amount of accessible mobile station per unit area (per km2).

- **Latency**: It can be identified as a time which required for receiving data packet which transmitted from the source such as base station or mobile station that is available in the network. (in ms).
- **Mobility:** It could be simply described top speed which truly matches with the required QoS and enables uninterrupted data transfer among radio nodes which may be affiliated to various network layers (in km/h).
- **Spectrum efficiency:** Represents the mean of data throughput per unit of spectrum resource (bit/s/Hz).

Heterogeneous system architecture should be established to increase the quality of provided service to the users to satisfy the requirements of above-mentioned criterions. Therefore, the next step is to advance our perspective towards to the cellular heterogeneous system architecture with efficient way to provide the criterions.

2.1.2 Cellular Heterogeneous System Architecture

When compared with previous generations of mobile communications, specifically 5G needs to require extremely high performance requirements in more diverse scenarios. In case of intensive undesired interference scenarios, creation of low power nodes with reduced cell size would generate an opportunity to accelerate flexible connection among BS and UE hence such interference would be hindered in terms of downlink and uplink directions. It could be stated that low power nodes should be placed in a denser way which simply called as "*Heterogeneous Network Architecture*", which means approximately one million connections per squared kilometer need to be supported. This scenario primarily focuses gathering data from smart devices which will increase in few years though uninterrupted communication and high QoS. Moreover, the main benefits of this scenario could be addressed as reduced power consumption, increased chances for more connections, increased quality of communication through small data packets and reduced costs [5, 16].

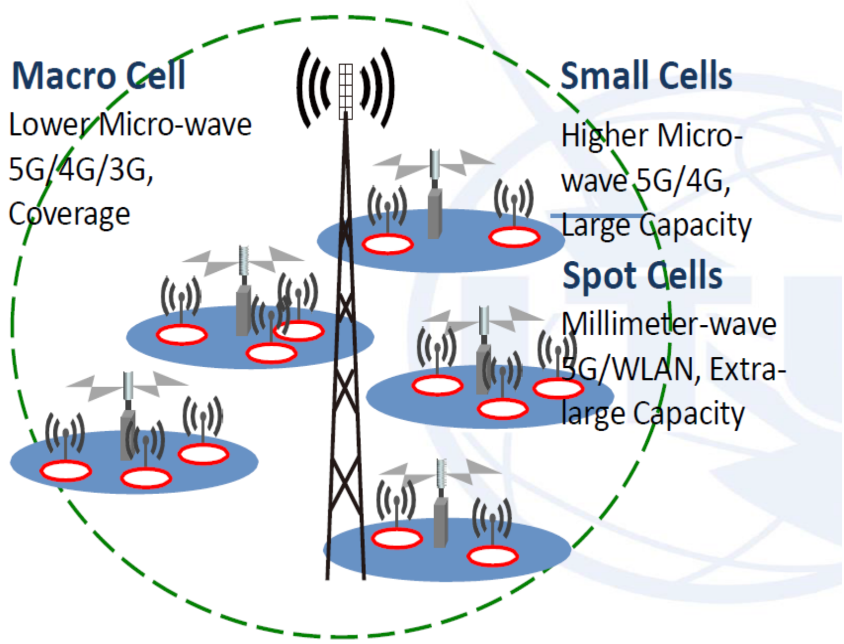

Figure 2.3: Exhibition of High Power (Macro Cells) and Low-Power (Small Cells) Base Stations Together Within a Heterogeneous Network Environment [18].

It could be signified that Heterogeneous Network (HetNet) topologies are formed with a mixed conventional high-power BS which could be named as Macro Cell (MaC) and pico-cell, Femto Cell, and/or relay nodes which previously mentioned in forms of low-power. In HetNet topology low-power nodes which could also indicated as *"Small Cells" (SmCs)* are overlaid within a MaC and demonstrated in Figure 2.3 below. Macro Cells serve large area because of having low frequencies. Base Stations also can be called as Evolved NodeB (eNodeB) in heterogeneous network which is specified by Generation Partnership Project (3GPP) for an LTE scenario. Unlike the Macro Cells (MaCs), SmCs are designed for higher frequencies where many advantages are consisting with reducing the cell-size [21]. In addition to these, it can be signaled that reuse of the same radio frequency could be helpful to expand the capacity of the network. Therefore, MaCs and SmCs share the same frequency spectrum in a HetNet scenario. Moreover, it is believed that mobile operators primarily prefer to engage with SmCs to stimulate and optimize their service coverage which in turn extend their capacity of network [15].

2.1.3 OFDM Framework in LTE

LTE-Advanced framework is based on Orthogonal Frequency Division Multiplexing (OFDM) foundation which gives excellent results for many reasons and this technique will take a crucial place for further improvements of mobile telecommunication as well as multiuser scenarios [15, 17, and 31]. Therefore, the present study is prepared based on OFDM frameworks.

Orthogonal Frequency Division Multiplexing (OFDM) is a competitor of Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA) where the transmitted signal is separated into multiple narrower sub-carriers, which are then transmitted in parallel-streams [31]. Transmitted sub-carriers never collide with each other due to orthogonally property where multi-carrier signals are used in different frequencies. OFDM gives an opportunity for two important aspects. First, Cyclic Prefix (CP) takes an effective role to mitigate the Inter Symbol Interference (ISI). Second, important point is the very closely spaced sub-carriers help to use available spectrum efficiently. It's beneficial to think about the signal in both the frequency and time domains. After coding and modulation, a transformed version of the complex-valued modulated signal, the physical resource element, is mapped on to a time-frequency coordinate system, the resource grid. The resource grid has time on the *x*-axis and frequency on the *y*-axis. The *x*-coordinate of a resource element indicates the OFDM symbols, which belong to time. The *y*-coordinate signifies the OFDM sub-carriers, which belong to frequency.

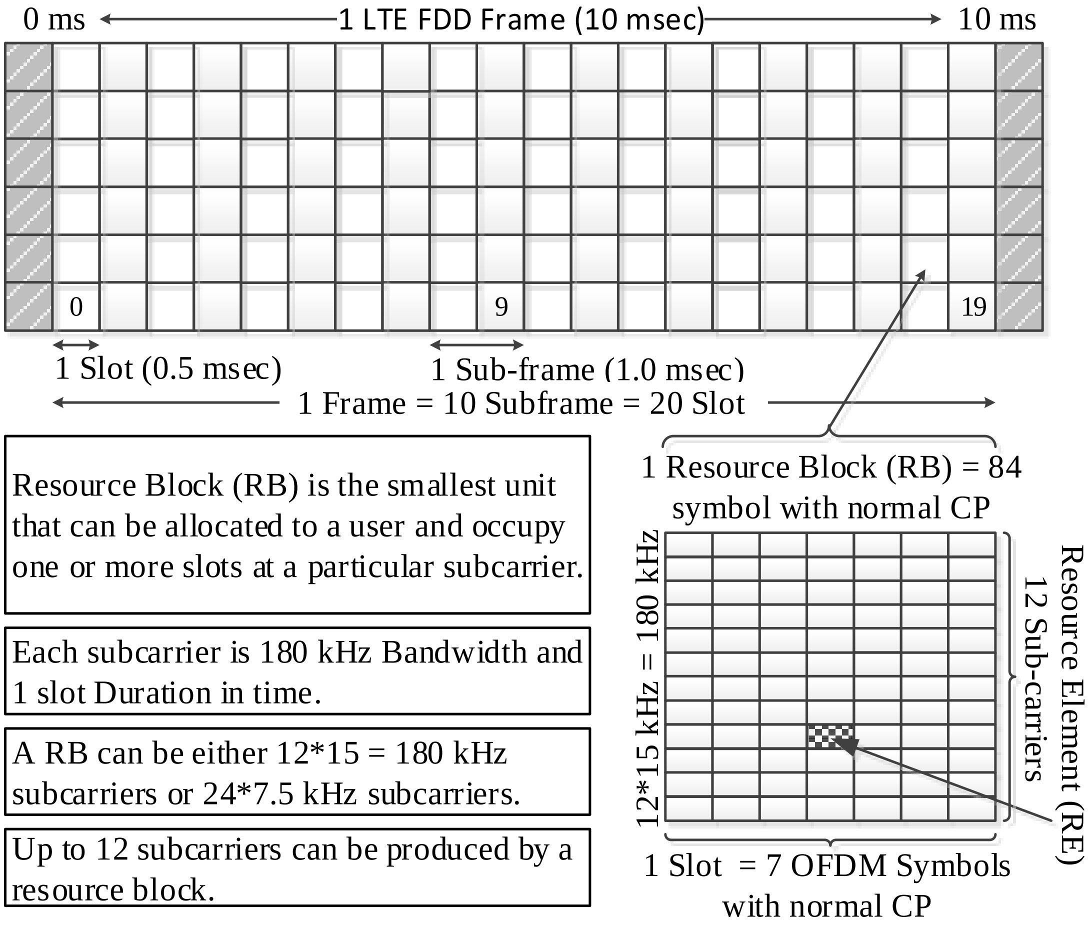

Figure 2.4: LTE Time Domain Frame Structure.

Figure 2.4 illustrates the LTE-Advanced frame structure model. It is clearly observed from the figure that the system is designed with 10-sec duration for each frame. Frames are made up of 10 sub-frames where each last 1-msec duration. Moreover, each sub-frame is divided into two slots and one slot is 0.5-msec long. Further enhancement of frequency dividing; give an opportunity to use either 6 or 7 symbols OFDM symbols in each slot. Number of OFDM symbols are associated with the length of CP either being normal (7 OFDM symbols) or extended (6 OFDM symbols) [19].

A Resource Element (RE) is placed at the intersection of an OFDM symbol and a sub-carrier. In addition, users who are communicating in such frameworks are allocated to specific appropriate sub-carriers for a duration that is pre-planned. Each sub-carrier has duration 15 kHz in the frequency domain. If normal CP option is considered, due to the fact that 1 sub-carrier contains 2 slots and 1 slot contains 7 OFDM symbols, 14 OFDM symbols are presented in per sub-frame. Further, Resource-Block (RB) characterization should be known clearly because of the importance for the user data stream allocation in such systems. It can be emphasized that RB is the smallest unit that can be assigned to a user. To approach more scientifically it can be stated that RB is the group of RE matched to 12 sub-carriers. In frequency domain, duration of RB is 180-kHz (12 by 15 kHz) and in time domain it can be specified as 0.5-ms slot. In the instance of normal CP with 7 symbols per slot, RE are exists in each RB. In the form of extended CP with 6 symbols per slot results with 72 RE.

2.2 Propagation Characteristic and Channel Modelling

The main aim of this section is to advance our understanding towards to medium between the BS and UE which can be referred to as *the "channel"*. Therefore, this section starts with the basic concepts of channel modelling to portray preliminary concepts. More specifically, this section purposes to push forward our understanding towards the conceptual frameworks of channel in detail.

2.2.1 Basic Concepts of Channel

It can be stressed that when transmitter and receiver antennae communicate, characteristics of wireless signal between the BS and UE is considerably affected due to various impairments in the channel. These impairments can be associated with the distance between the BS and UE, the path(s) travelled by the signals and the surrounding environments properties (such as buildings and other objects). The received signal can be modelled by considering the transmitted signal, the medium between the transmitter (the channel) and the receiver. This model of the medium is referred as **channel model**.

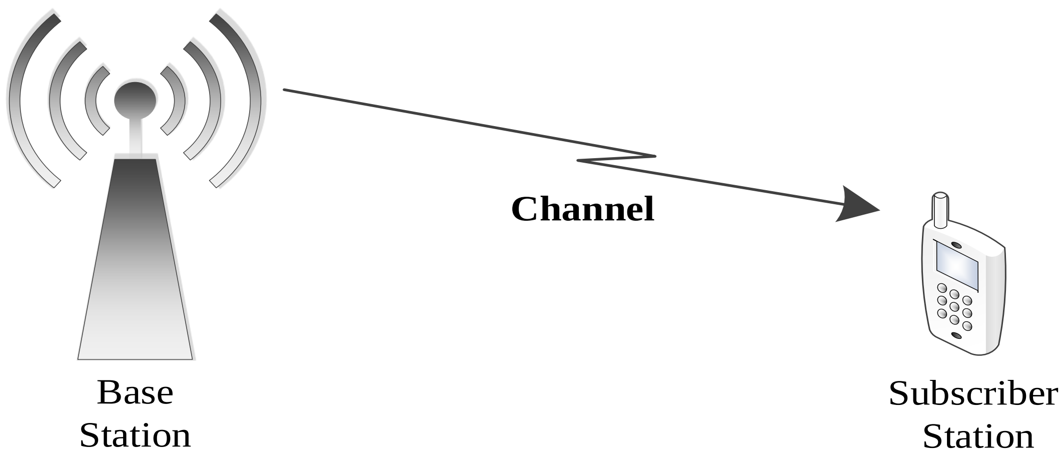

Figure 2.5: A Simple Transmitter, Channel and Receiver Model.

The channel shown in Figure 2.5 can be substantially characterised by its Impulse Response (IR) or the magnitude of the IR called the Power Delay Profile (PDP). For this reason, received signal can be obtained by considering the convolution of the transmitted signal and channel impulse response. Moreover, convolution in time domain can be transformed into multiplication in the frequency domain. According to these, the transmitted signal, after propagation through the channel can be expressed as following equation.

$$Y(f) = H(f)X(f) + N(f) \tag{2.1}$$

where $H(f)$ indicates the **channel frequency response**, $X(f)$ is the transmitted signal $Y(f)$ is the received signal and $N(f)$ is the Additive White Gaussian Noise or thermal noise spectrum. It should be specified that all symbols are functions of frequency, f [36].

2.2.2 Small Scale Fading Effects Due to Multipath Delay Spread

In the wireless mobile communication, small scale fading is also referred to as short term fluctuations in the signal characteristics at the channel output. It can be specified that the effect of small scale fading is depending on the relationship between the channel parameters which can be expressed as bandwidth, symbol period etc. Moreover, the word fading is commonly used to describe considerable attenuation in the received signal amplitude such that the system performance is notably hindered.

The channel parameters such as rms delay spread and doppler spread also have meaningful degradation in the system performance. In addition, the fact that multiple path originating from the transmitter may arrive at the receiver due to reflection, diffraction and scattering of the transmitted signal hence producing a multipath communication channel. The resulting channel output can show a big variation in amplitude and phase depending on the magnitude and phase differences between different individual paths, which can be added constructively or destructively. The dynamic range of the received signal power can change between 0 and 100 dB depending on the terrain and the phase can change between 0 and 2π [36, 37].

It might be indicated that fading is categorized based on the linkage among the signal parameters and the channel parameters. The term of coherence time of channel is a measure of how quickly the channel response decorrelates. When the symbol duration is smaller than the coherence time the fading is called as slow fading. When the symbol duration is exceeding the coherence time the fading is called as fast fading. Another categorization of the fading process is related with the tie among the delay spread of the channel which is a measure of its time dispersiveness and the duration of symbol. When the symbol duration is exceeding the delay spread the fading is characterized as flat fading. Moreover, selective fading occurs when delay spread is exceeding the symbol duration.

The current study concentrates on the flat fading channel model. Therefore the next section of the report will briefly explain the concept of flat fading and channel parameters and channel probability of density function graph will be exhibited to create better understanding towards to concept.

2.2.3 Rayleigh Flat Fading Channel Model

It could be stressed that in case of having constant gain and linear phase response within channel bandwidth which transmitted signal exceeds the channel bandwidth, then received signal will undergo flat fading. In flat fading case the characteristics of the mutlipath structure is crucial as it enables transmitted signal to be protected at the receiver. The strength of the received signal is closely associated with time. To be more accurate, the strength of the received signal will change by the time. The reason behind this is the volatility of channel gain due to mutlipath effect.

Figure 2.6 demonstrates the channel gain which is changing over time and such change will also cause an amplitude change at the receiver. It might be mentioned that over time, received signal $r(t)$ changes its amplitude. However, bandwidth of the transmission remains constant. In a flat fading channel, transmitted signal duration is much larger than multipath time delay spread of the channel. The channel which can be symbolized as $h_b(t,\tau)$ then becomes $h_b(t,0)$ in case of flat fading channel model. In other words, it can be assumed that single delta function is $\tau = 0$ which means there is no excess delay.

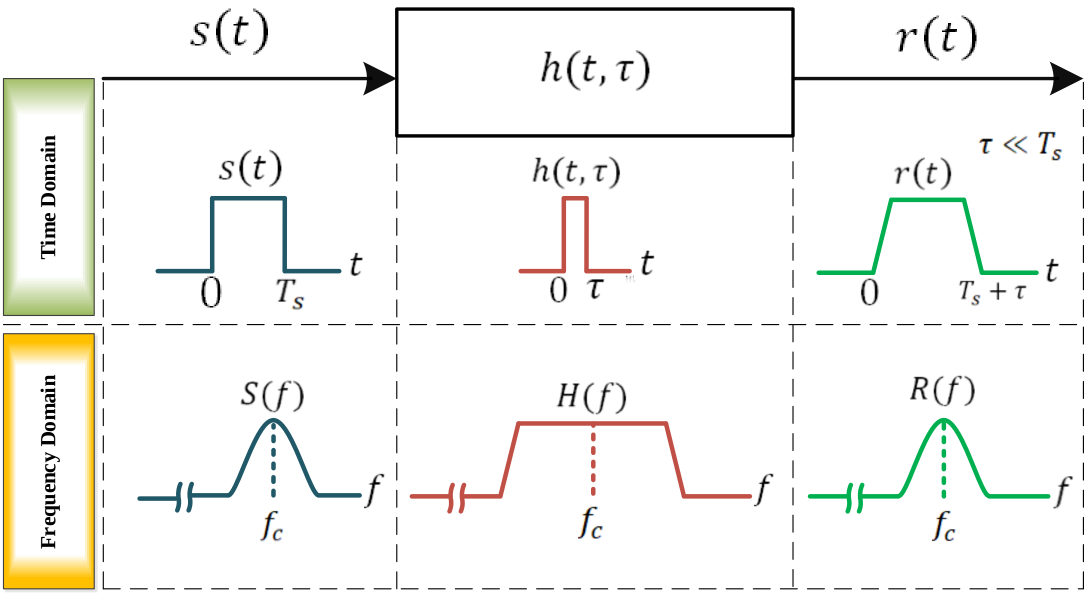

Figure 2.6: Flat Fading Channel.

Flat fading channels could also be referred to as *amplitude varying channels* or *narrow band channels* as spectrum of the applied signal is narrow when compared with the spectrum of the flat fading channel. It could be stated that an ordinary flat fading channel models may lead to deep fades of the entire channel output. Therefore, to satisfy required BER performance more transmitter power is needed to mitigate undesired impacts of the fades.

Moreover, the gain allocation for transmitting the signal plays a promiment role to shape radio link. It should be ephasized that the Rayleigh distribution is commonly used in flat fading model for amplitude distribution. The Rayleigh flat fading channel model generates an amplitude which changes with time according to the Rayleigh distribution.

In current study, the above mentioned Rayleigh flat fading channel model without Doppler shift is considered as medium between the BS and UE. It could be specified that 6 paths have been executed to the transmit signal through randomly realized with exponential power delay profil by a dynamic range of 20 dB. Moreover, Table 2.1 illustrates a detailed information where power delay profile and the path powers in terms of dB can be observed for each path.

Table 2.1: Rayleigh Channel Model.

Path Powers	1	2	3	4	5	6
Delay (μs)	0	0.11	0.22	0.33	0.44	0.55
Power (dB)	0	-10	-13.3	-15	-16	-16.7

Furthermore, the used Rayleigh distribution with flat fading channel model can be simulated as Probability Density Function (PDF) as shown in Figure 2.7.

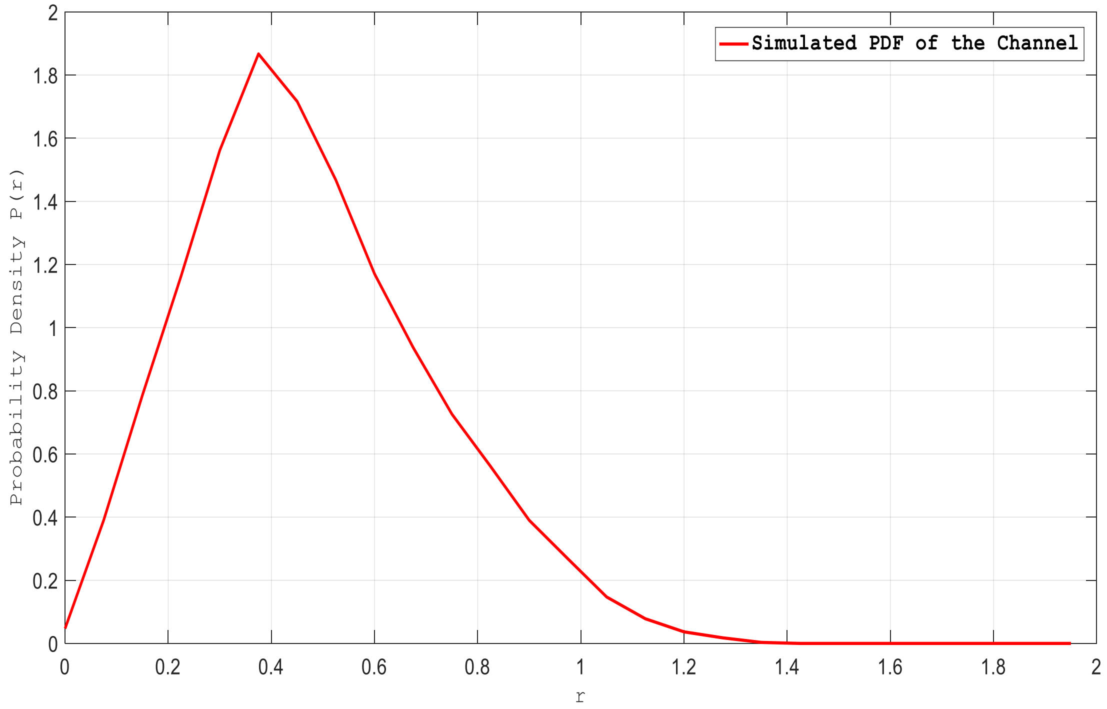

Figure 2.7: Simulated PDF of the Rayleigh Flat Fading Channel.

2.3 Single-User (SU) IMT System

To create better understanding of the multiuser system, it is critical to explain the primary dynamics of Single-User IMT System as a first step. Then the current study will emphasize the major characteristics of the multiuser transmitted signal model and its detection.

2.3.1 Transmitted Signal Model

In this part it is aimed to present traditional Single-User OFDM communication systems as well as their block diagram and mathematical system model. Figure 2.8 below exhibits the simplified Single-User block diagram with OFDM system [24]. It should be clarified that the detail information about the each process will be given in Chapter 3. Assume that there is total number of U sub-carriers to be transmitted and one sub-carrier provides service to only one user. The direction of transmitted DL signal could be expressed from eNodeB to UE.

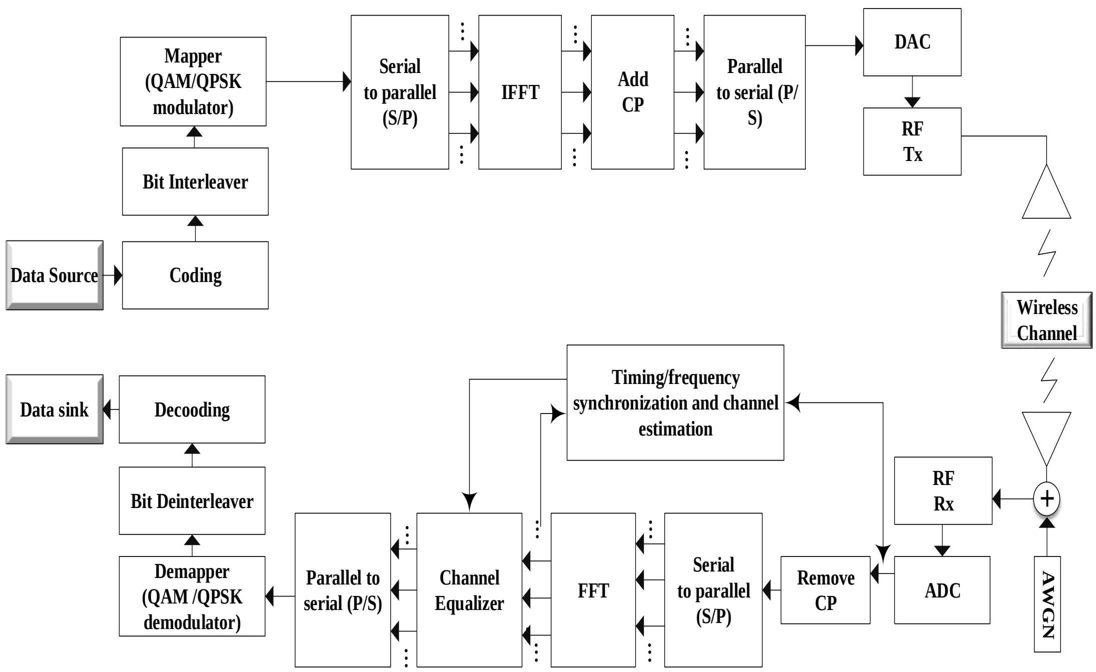

Figure 2.8: Simplified Single-User OFDM Block Diagram.

The data stream in the DL and the main source of the data stream could be mentioned as i-th eNodeB which assigns U_i resource blocks given by [3]. The formula which is applied to compute U_i could be lamented as Equation (2.2).

$$U_i = {}^{U}/_{B} \tag{2.2}$$

Where U represents the total number of Resource-Blocks (RB) in the system and B denotes the number of eNodeB to be served which postulated by Equation (2.2). It is critical to overcome the Inter Symbol Interference (ISI). One way to avoid ISI could be signified by adding Cyclic Prefix (CP) right after each Number of Inverse Fast Fourier Transform (N-IFFT). It is crucial to indicate that this strategy functions well when the length of the CP is exceeding the length of the channel delay spread. The transmit signal which derived from i-th eNodeB could be named as $\mathbf{X}_i$. It can be mentioned that $\mathbf{X}_i$ is sent through noisy multipath channel until received $\boldsymbol{Y}_{ik}$ signal by k-th User Equipment (UE). The number UE could be formed as k symbol and the receive signal at the UE can be formulized as in Equation (2.3).

$$\boldsymbol{Y}_{ik} = \mathbf{X}_i\mathbf{H}_{ik} + \mathbf{Z}_k + \mathbf{Z}_{k,\mathrm{I}}, \qquad k = 1, \dots, K \tag{2.3}$$

Where $\mathbf{H}_{ik}$ is matrix with $N_T \times N_R$ dimension complex multipath channel coefficients between i-th eNodeB and k-th UE. To deepen our understanding regarding the formula, N_T could be outlined as number of transmit antennas, N_R represents the number of receive antennas and $\mathbf{Z}_k$ stands for Additive White Gaussian Noise (AWGN) with zero mean and unit variance at k-th UE, whereas $\mathbf{Z}_{k,\mathrm{I}}$ could be expressed as CCI which influencing the transmission at the k-th UE due to I-th eNodeB which use the same frequency. In other words, k-th UE which could be called as “selected user” that planned to communicate with base station is suffered from CCI which occurred by undesired users within the HetNet.

2.3.2 The Single-User Detector

Interference could take place in forms of sharing the same signal in Single-User (SU) case and the SU detector gives opportunity to detect as well as treat the signal of desired user and with the help of estimations, it declines the level of interfering signals [29].

Single-User Detector demonstrated by Figure 2.9, highlighted that channel estimation is established by all cooperating UEs as well as combining and equalization is carried only at the targeted signal of UE. The samples of received signal $\boldsymbol{Y}_{ik}$ and the CSI are sent to all cooperating UE through a near ideal backhaul [21, 24].

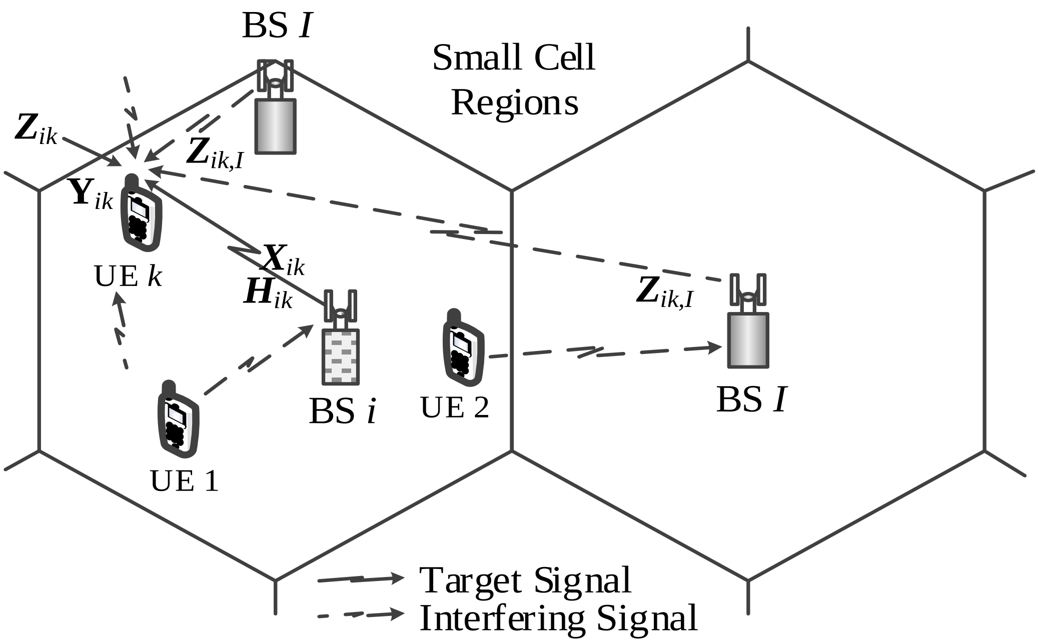

Figure 2.9: The Scenario for the Single-User System Model.

The received signal denoted by $\boldsymbol{Y}_{ik}$ is combined and equalized at the Central Processing Unit (CPU) by using the cooperatively estimated CSI which denoted as $\widetilde{\boldsymbol{H}}_{ik}$. Finally, i-th eNodeB signal $\widetilde{\boldsymbol{Y}}_{ik}$ can then be estimated by employing Maximal Ratio Combining (MRC) as in Equation (2.4).

$$\widetilde{\boldsymbol{Y}}_{ik} = \sum_{k=1}^{N_T N_R} \mathbf{w}_{ik} \boldsymbol{Y}_{ik} = \mathbf{H}_k^{i*} \boldsymbol{Y}_{ik} \tag{2.4}$$

Where, $\mathbf{W}_i = \sum_{k=1}^{N_T N_R} \mathbf{w}_{ik} = \mathbf{H}_k^{i*}$ could be identified as a complex conjugate of i-th eNodeB channel coefficients. Following MRC, the i-th eNodeB effective CSI stands for equalization, $\mathbf{H}_{\text{eff}}^{i}$, which can be illustrated as follows:

$$\mathbf{H}_{\text{eff}}^{i} = \sum_{k=1}^{N_T N_R} \mathbf{H}_k^{i} \mathbf{H}_k^{i*} \tag{2.5}$$

In Equation (2.5), $\mathbf{H}_k^{i}$ represents the channel state information for k-th UE due to i-th eNodeB and $\mathbf{H}_k^{i*}$ is its complex conjugate. Moreover, by using the Least Squares (LS) channel estimation which stressed in the study of [22], where the pilot symbols are transmitted on 4-th slot of the transmission time interval. Besides of these, channel impulse response at the k-th UE could be gathered. Asides of these, for conformation the LTE standards, Zero Forcing (ZF) equalization is appointed where the equalizer output will be illustrated by the following formulation Equation (2.6).

$$\mathbf{V}_{ik} = \mathbf{W}_{\text{ZF}}^{i} \widetilde{\boldsymbol{Y}}_{ik} \tag{2.6}$$

Where the ZF equalizer coefficients are highlighted by the formula in Equation (2.7).

$$\mathbf{W}_{\text{ZF}}^{i} = ((\mathbf{H}_{\text{eff}}^{i})^{\text{H}} \mathbf{H}_{\text{eff}}^{i})^{-1} (\mathbf{H}_{\text{eff}}^{i})^{\text{H}} \tag{2.7}$$

After demodulating and channel decoding, the original data symbols are almost obtained. It can be stated that despite the employed estimation and advanced detection methods for SUD environment, mitigating the existing interference and serving high spectral efficiency are not possible due to growing data demand in HetNet.

The coming sections of the study will emphasize proposed detection and estimation methods for multi-user communication system in 5G Heterogeneous network.

2.4 Multi-User (MU) IMT System

The main aim of this section is to explore the Multi-User MIMO model in detail and compare it with single user systems. This section will begin by drawing a brief definition about multi-user.

2.4.1 Multi-User Systems

It can be stated that within the Single-User MIMO system, a point-to-point high data rate transmission can be promoted by spatial multiplexing approach with the help of spatial diversity gain. However, most of the communication systems engage with multiple users that are using the same radio resources or bandwidth. MU-MIMO could be also perceived as a MIMO system which in turn generates an opportunity to the different users within the same network to transmit their data packets on the same resource blocks while each of them could have single antenna in their mobile devices. To be more accurate, in the MU infrastructure, the base station schedules all of data by segregating both uplink transmission data and downlink data for each UE within the same sub-frame and on the same resource blocks. It could be indicated that simultaneously scheduling the pairs of multiple MU-MIMO is closely associated with the number of resource blocks which are existing in the system bandwidth. It could be mentioned that pairing might be influenced by several factors such as power control, quality of individual channels, and profile of interference. It is vital to indicate that these factors also play a key role on the decisions about time slot. Figure 2.10 shows ordinary Multi-User schemes which introduced for MIMO-OFDM communication context, which single base station serves individual user data to multiple-user.

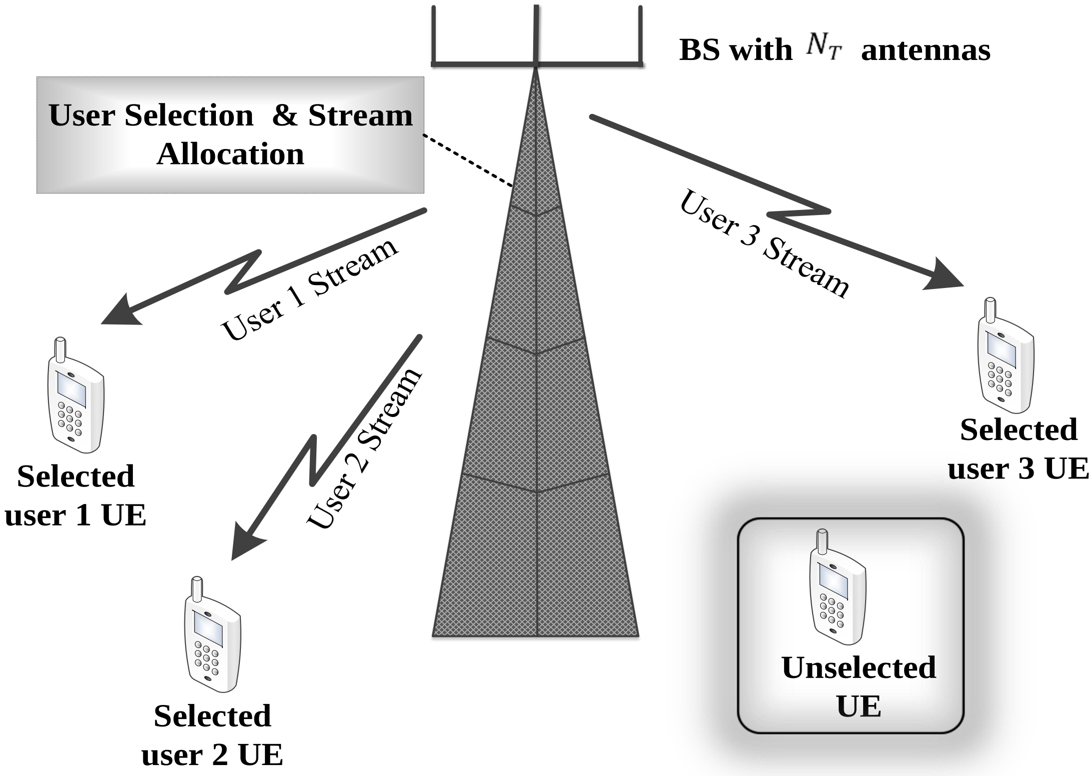

Figure 2.10: Multi-User MIMO Communication System.

Furthermore, Figure 2.10 also demonstrates that three out of four users are picked, and they are allowed to share communication resource and forms time/frequency planes. When CCI is compared among Single-User Detectors (SUD) and Multi-User Detectors (MUD) it could be stressed that SUD fails to realize and to mitigate the CCI when UEs and BSs are using the same frequency bands [25]. The fundamental principle of the MUD technique is the elimination of the effects of CCI. To overcome the undesired effects, “simultaneous” detection of all users' signals can be realized rather than cancellation of interfering signals in SmC networks [30]. One of the best features of Multi-User systems can be specified as the existence of multiple parallel data streams. To be more precise, in ordinary SU frameworks, time and frequency resource division is provided as mentioned earlier in Section 2.1.3, and one RB is assigned per user. Therefore, only one RB is becoming active. However, in MU systems, multiple independent parallel data transmissions take place which implicitly means that multiple RB can become active simultaneously [19, 32].

2.4.2 Transmitted Signal Model

It could be stressed that in the proposed Multi-User system, the number of transmit and receive antenna are taken as 1 for simplicity (Hence a Single Input Single Output - SISO System). The current study can be easily extended to represent MIMO System with N_T transmit and N_R receive antennas.

During the communication, each *k*-th user data sequence is coded with specially generated different code which can be symbolized as $\boldsymbol{c}_k$, and interleaved by $\boldsymbol{\Pi}_k$. Then, coded and interleaved signal sequence mapped into the sequence of transmitted complex signal by providing different modulation techniques. Furthermore, N_{fft} indicates size of Fast Fourier Transform (FFT). Moreover, T_g represents the amount of guard time (CP). After modulation, CP added to the signal and IFFT used with N_{fft} size. The generated transmitted sequence size for each user after the addition of guard time can be expressed as $N_{fft} + T_g$ [35]. It could be noted that detail information about mentioned system parameters will be given in Section 3.1.

The transmitted signal which derived from eNodeB could be represented as $\mathbf{x}_k \in \mathbb{C}^{1\times(N_{fft}+T_g)}$ whereas; $\boldsymbol{y}_k \in \mathbb{C}^{1\times(N_{fft}+T_g)}$ is the received signal at the Mobile Station (MS) for *k*-th user. The range of users can be specified as *k* = 1, 2, 3… *K*. To represent the signal at the channel output, it could be stated that for each user coefficient of channel has 1x1 as a matrix size. It could be indicated that flat fading complex channel was employed for the current study. The channel coefficient which appointed for the current study could be exhibited as $\mathbf{H}_k \in \mathbb{C}^{1\times 1}$ which denotes the channel gain between Base Station and k-th Mobile Station (MS). The Signal at the channel output which assigned for the current study can be expressed by Equation (2.8).

$$\boldsymbol{y}_k = \sum_{k=1}^{K}[\mathbf{H}_k \mathbf{x}_k] + \mathbf{z}_k \ , \quad k = 1, 2, \dots, K \tag{2.8}$$

Equation (2.8) can be expanded by the following equation;

$$\boldsymbol{y}_k = (\mathbf{H}_1\mathbf{x}_1 + \mathbf{H}_2\mathbf{x}_2 + \mathbf{H}_3\mathbf{x}_3 + \ \dots + \ \mathbf{H}_K\mathbf{x}_K) + \mathbf{z}_1 + \mathbf{z}_2 + \mathbf{z}_3 \dots \mathbf{z}_K \tag{2.9}$$

Where $\mathbf{z} \in \ \mathbb{C}^{1\times(N_{fft}+T_g)}$ stands for the Additive White Gaussian Noise (AWGN) with zero mean and unit variance $\sim \mathcal{CN}(0,1)$ in the receiver of k-th user. Besides of these, this equation could be expanded in forms of matrix which is illustrated by Equation (2.10).

$$\begin{bmatrix} \boldsymbol{y}_1 \\ \boldsymbol{y}_2 \\ \vdots \\ \\ \vdots \\ \boldsymbol{y}_{K-1} \\ \boldsymbol{y}_K \end{bmatrix} = \begin{bmatrix} \mathbf{H}_1 \\ \mathbf{H}_2 \\ \vdots \\ \\ \vdots \\ \mathbf{H}_{K-1} \\ \mathbf{H}_K \end{bmatrix} \mathbf{x} + \begin{bmatrix} \mathbf{z}_1 \\ \mathbf{z}_2 \\ \vdots \\ \\ \vdots \\ \mathbf{z}_{K-1} \\ \mathbf{z}_K \end{bmatrix} \tag{2.10}$$

In Equation (2.10), each row data index belongs to a different active user in the Multi-User system to gather data simultaneously. Moreover, $\mathbf{x}$ which is shown by Equation (2.11) can be demonstrated in matrix form where T denotes transpose as following.

$$\mathbf{x} = [\ \mathbf{x}_1 \ \ \mathbf{x}_2 \ \dots \ \mathbf{x}_{K-1} \ \ \mathbf{x}_K \ ]^T \tag{2.11}$$

Block diagram which is signalled by Figure 2.11, portrays that at the multiuser system, data stream is generated independently for each user, which passes through flat fading channel. Afterwards, for each user different noise is added at the receiver which is demonstrated by the following figure.

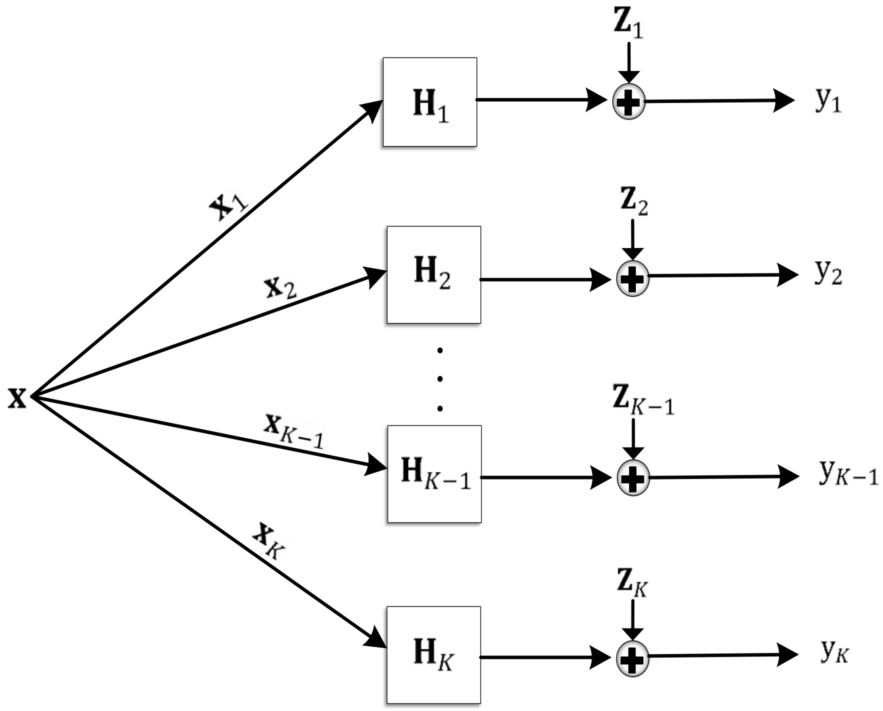

Figure 2.11: Channel Block Diagram for Multi-User System.

2.4.3 The Multi-User Detector

As previously indicated the current study will apply to the multiuser inversion technique to explore users' transmitted signal. Therefore, this section is aiming to present the signal model at the received (UE).

It might be stated that in Single User MIMO systems, undesired noise can be mitigated by employing the Zero Forcing (ZF) pre-equalization criterion. However, ZF in MU-MIMO systems could be called as Channel Inversion (CI) Technique which implies that to detect transmitted signal inverse version of the channel is considered. The estimation technique to detect transmitted signal through CI is published in the literature. The formula to detect transmitted signal though CI could be explained as follows.

Let $\tilde{\mathbf{x}}_k$ indicated *k*-th estimated user signal which could be called as original signal approach, while $\mathbf{H}_k \in \mathbb{C}^{1\times 1}$ denotes complex channel matrix among the BS and *k*-th UE. Received *k*-th user signal has been exhibited in Equation (2.12) with detected and estimated signal [30].

$$\boldsymbol{y}_{k\,=} = \mathbf{H}_k \begin{bmatrix} \widetilde{\boldsymbol{x}}_1 \\ \widetilde{\boldsymbol{x}}_2 \\ \vdots \\ \\ \vdots \\ \widetilde{\boldsymbol{x}}_{K-1} \\ \widetilde{\boldsymbol{x}}_K \end{bmatrix} + [\mathbf{z}_k]\,, \quad k = 1, 2, \dots, K \tag{2.12}$$

The received signals for all users can be illustrated in matrix forms by Equation (2.13)

$$\underbrace{\begin{bmatrix} \boldsymbol{y}_1 \\ \boldsymbol{y}_2 \\ \vdots \\ \\ \vdots \\ \boldsymbol{y}_{K-1} \\ \boldsymbol{y}_K \end{bmatrix}}_{\substack{Received \\ Signal}} = \underbrace{\mathbf{H}_k}_{\substack{Channel \\ Gain}} \underbrace{\begin{bmatrix} \widetilde{\boldsymbol{x}}_1 \\ \widetilde{\boldsymbol{x}}_2 \\ \vdots \\ \\ \vdots \\ \widetilde{\boldsymbol{x}}_{K-1} \\ \widetilde{\boldsymbol{x}}_K \end{bmatrix}}_{\substack{Transmitted \\ Signal}} + \underbrace{\begin{bmatrix} \mathbf{z}_1 \\ \mathbf{z}_2 \\ \vdots \\ \\ \vdots \\ \mathbf{z}_{K-1} \\ \mathbf{z}_K \end{bmatrix}}_{\substack{Noise \\ Signal}} \tag{2.13}$$

In Equation (2.13), the received signal $\boldsymbol{y}_k$ at each UE is a vector of $\boldsymbol{y}_k \in \mathbb{C}^{1\times(N_{fft}+T_g)}$. Thanks to the channel inversion method where the transmitted signal $\boldsymbol{y}_k$ is multiplied by the inverse of the channel matrix to obtain estimates of $\mathbf{x}_k$ which are simultaneously detected [23].

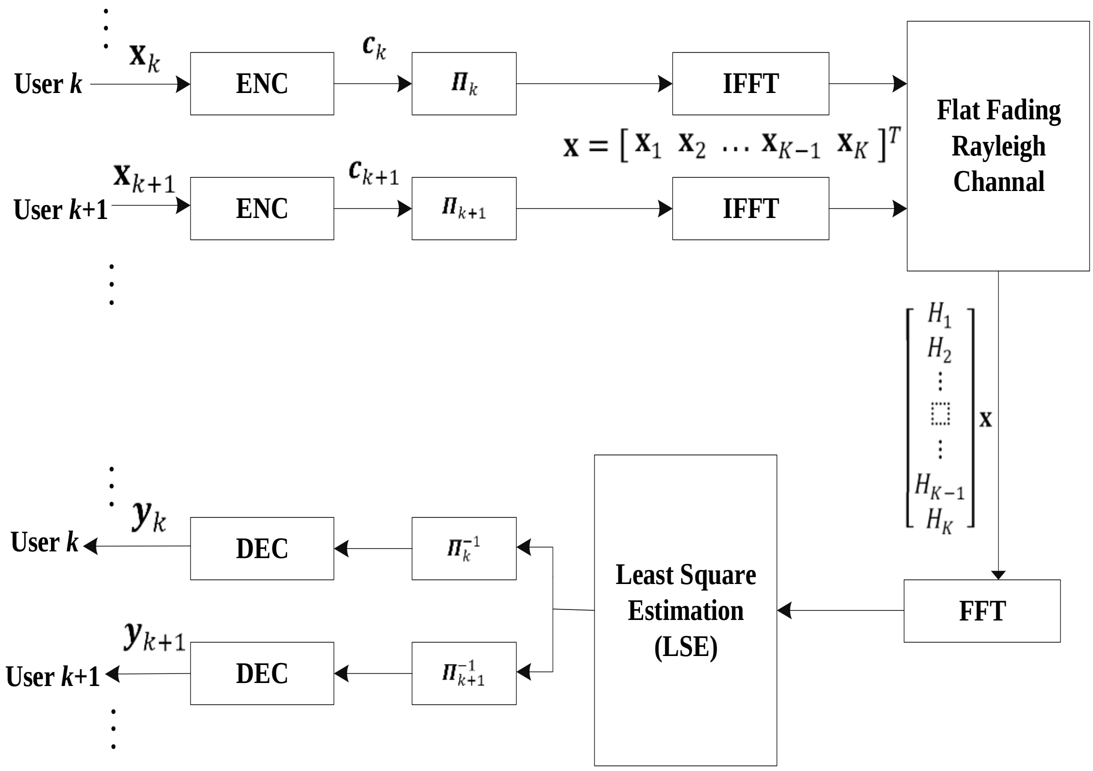

Figure 2.12: Multi-User Detector Block Diagram.

Multi-user detector can be also seen as block diagram in Figure 2.12. It can be seen from the figure that, all transmitted signals can be generated and processed independently. Then received signal $\boldsymbol{y}_k$ can be obtained simultaneously.

Chapter 3

SIMULASTION SYSTEM MODELLING AND PERFORMANCE ESTIMATION

The main objective of this chapter is to briefly highlight the stages followed to set up the system which is assigned for the simulation and indicating the most critical parameters which used in the simulation to observe various Multi-User scenarios. The chapter also aims to conclude the results of the simulation. As a first stage, the program which includes the parameters of the Single-User system that already existing for Long Term Evaluation Advanced (LTE-A) is transformed to Multi-User to create independent multiple data streams for each user. Then user selection approach is practiced by considering CSI feedback which obtained from each user to boost the quality of communication. In addition to these Multi-User Detection (MUD) is employed to detect data which transmitted for each user by considering inversion of channel technique.

3.1 Simulation System Parameters

The system model is described in Figure 2.12 the number of total users in the system where the users attempt to receive/transmit data selected as K=10. The transmit message is generated randomly and independently for each UE where user range in the system can be identified as $k = 1, 2, \ldots, K$ and K denotes the total number of user as mentioned earlier on.

In order to generate individual independently message for each K, the number of transmitted frame has taken as 250 for reliable transfer in simulation. Moreover in simulation, 8 packets in each frame that can be demonstrated as F_s and in each packet has defined P_s=188 bytes are used. It may be useful to remind that each byte is occurred with 8 bits information that characterized by N_{ps}. To express more detail about the generated transmit signal, it occurs total 12,032 bits in each frame which is obtained from multiplication of number of packet size, number of bytes and number of bits where can be formulated as $F_s * P_s * N_{ps}$.

Then, six different changes are applied to each UE with considering the Digital Video Broadcasting (DVB) in LTE standards before sending it through OFDM structure [30].These changes can be expressed as randomization for energy dispersal and transport multiplex adaptation, outer coding (i.e. Reed-Solomon encoding), outer interleaving (i.e. convolutional interleaving), inner coding (i.e. punctured convolutional code), inner interleaving (either native or in-depth), mapping and modulation [26, 27]. These steps can be expressed briefly as follows.

The data in harmony with scrambler architecture sufficient binary transitions is ensured by the randomizing. In outer coding section, by taking advantage of Reed-Solomon coding, 16-byte redundancy byte is added to previously mentioned 188-byte packet size and then transmission stream will result as 204-byte. After Reed-Solomon coding, transmit signal sequence has shaped as 8 by 204 where 8 is the number of packet and 204-bytes are used for one packet. The Reed Solomon code can be specified as RS (204,188, t = 8). In section of outer interleaving, packets will be error protected with depth I = 12 by a user-specific interleaver $\boldsymbol{\Pi}_k$ [26, 27 and 35].

In inner coding, punctured convolutional codes used to correct errors which based on a mother convolutional code of rate 1/2 with 64 states. Inner coding generally is applied to decrease the redundancy of the mother code. Furthermore, this coding technique is very useful for mitigating undesired ISI which is efficient way to get high performance due to existing low errors. For instance, it can be detailed that 1/2 rate polynomials generator is an encoder which responsible to change one-bit symbols in the input to 2-bit symbols as output [26, 28]. Moreover, code can be used in different purposes by setting diverse punctured convolutional code such as 2/3, 3/4, 5/6 as well as 7/8. In current study, 3/4 coding is considered as inner coding. For the case of inner interleaving, it can be expressed as two parts where with bit-wise inter-leaver and symbol-wise inter-leaver [28].

To finalize the transmission process, constellations and the mapping technique is applied to the each generated UE signal $\mathbf{x}_k$, by using different types of OFDM modulation techniques such as 4-QAM, 16-QAM for mapping signal sequence to correspond sub-carriers. After that, Inverse Fast Fourier Transform (IFFT) operation have been applied to match the corresponding time wave form where FFT size N_{fft} have taken as 2048 for executing symbols that coming to IFFT operation. As result of IFFT operation, signal output become N_{fft} time sample. Then, to avoid Inter Symbol Interference (ISI) Guard interval insertion has been applied which is also well known in OFDM basics as Cyclic Prefix (CP). Cyclic addition extension size in the prefix that can be symbolized as $T_g = 512$ is employed to start at each quaternary (1/4) sample. The length of cyclically extended output sample 2560 can be formulized as $N_{fft} + T_g$ [28]. Then, a parallel-to-serial-converter has been used at transmitter output and output samples transmitted through a Rayleigh flat fading channel. Effects of channel model are added to each user' transmitted signal. Then, by providing the parallel transmission to the signal which is in matrix form as shown by Equation (2.11) is send throughout the channel. Furthermore, Additive White Gaussian Noise (AWGN) added to the each of user separately signal.

To observe different scenarios, active user numbers N are selected as 2, 4 and 8 out of K user. It could be expressed that "*active users*" are selected for allowing communication according to their channel situation. It can be highlighted that CSI play an important role to serve data stream while determining active users. CSI gives knowledge about the channel condition which is between the UE and BS in the UL direction. After the channel process which transmitted signal passed through channel, active users are selected in the system to eliminate some user with using users' CSI by the eNodeB.

Due to existing poor channel quality, this strategy is a promising solution to mitigate the user who has bad channel condition. Active users are selected by considering CSI for each user and sorting the channel gains. The users who have good condition out of all attempting users are assigned to communicate. The channel gain has been calculated for all users who are attempting to communicate with eNodeB by formulized as $|\boldsymbol{h}_k|^2$ where $k = 1, 2 \ldots K$ and K denotes the total number of users in the system. After calculation of each k users' channel gain by taking advantage from the CSI feedback, K users have been sorted with descending order according to their channel quality. Then, N numbers of active users who have the higher channel norm values are selected out of K for increasing the performance of communication. In current study, N has taken as 2, 4 and 8 for observing different multiuser scenario where K=10.

It is worth mentioning this detail that, transmitter-side actions are fundamentally applied at receiver-side [10, 20]. At the receiver side, Serial-to-parallel-converter and CP removing have been executed for each signal that belongs to different multi-users. Then, N_{fft}-point FFT converted signal into frequency domain from the time domain. Least Square (LS) channel estimation technique has been implemented to overcome channel scatterings and distortions with using pilot symbols or preambles that known to both transmitter and receiver. Thus $\tilde{\mathbf{x}}_k$ has been obtained [22].

Then, by using MUD technique presented in this thesis have been employed to detect simultaneously of each user data from parallel transmitted multiple users' data. Channel inversion is considered to detect all active Multi-Users signals. It can be stated that all users' data have been obtained in matrix form as previously shown by Equation (2.14). After that, same six steps which are applied in the transmitter side for DVB requirements are also executed receiver side to obtain all users' signals accurately.

3.2 Simulation Results

In this section, simulation results will be presented by considering 3 different scenarios to discuss the Bit Error Performances (BER). These scenarios can be specified as following; First, the Single-User by using Single-User Detection (SUD) technique has been considered as benchmark case which can be stated as the optimum case for BER performance evaluation. As a second case, SUD will be assessed in Multi-User environment and its performance will be compared with the benchmark case. Finally, Multi-User will be simulated by providing Multi-User Detection and its BER performance will be compared with the performance of Single-User SUD. Moreover, a detailed information regarding parameters of simulation system will be provided to deepen understanding about the findings of the study. In addition to all these, findings of the will be demonstrated on the basis of schematic representations and will be discussed by relying 3 different scenarios. To be more accurate, during transmission process, some parameters which assigned for the simulation were evaluated as same in terms of conditions. These system parameters can be expressed as the following; (a) Number of randomly and independently generated signal sequence for each user, (b) Size of frame, (c) Coding rate for inner and outer coding, (d) size of IFFT, (e) Cyclic-Prefix size, (f) Size of FFT, (g) Channel property, (h) Modulation technique, (i) Estimation method and lastly (j) Inner and Outer interleaver. Table 3.1 shows the system parameters employed in simulation for three scenarios.

Table 3.1: Simulation System Parameters for Three Different Scenarios.

PARAMETERS	SU-SUD	MU-SUD	MU-MUD
Number of UE (*K*)	1	10	10
Number of selected UE (*N*)	1	2, 4 and 8	2, 4 and 8
Transmit signal size	1x2560	10x2560	10x2560
Channel Property	Rayleigh Channel without Doppler shift	Rayleigh Channel without Doppler shift	Rayleigh Channel without Doppler shift
Size of Frame	250	250	250
Reed Solomon Outer Code Rate	188/204	188/204	188/204
Outer Interleaving	Depth with $I = 12$	Depth with $I = 12$	Depth with $I = 12$
Convolutional Inner Code Rate	3/4	3/4	3/4
Inner Interleaving	Depth with $I = 12$	Depth with $I = 12$	Depth with $I = 12$
Size of Cyclic Prefix	512	512	512
Size of FFT	2048	2048	2048
Estimation method	Least Square	Least Square	Least Square
Modulation Technique	4-QAM, 16-QAM	4-QAM, 16-QAM	4-QAM, 16-QAM

3.2.1 BER versus SNR Performance Estimation for SU-SUD System

Single-User systems have been used for numerous applications in Orthogonal Frequency Division Multiplexing (OFDM) based communication frameworks. The system model described in Section 2.3 which is based on Single-User OFDM has been applied for obtaining the SU-SUD result of performance. The single user detector should give the optimum BER performance in case of being one user who communicates in the system. In this scenario, SUD mechanism is responsible to detect only one user's signal in the system. The reason for obtaining best performance in SU-SUD can be specified as existing low level of Co Channel Interference due to having no interfering-user to share same resource.

The performance result in terms of BER versus SNR of single active user had been tested though employing single user detector (which considered as benchmark case) could be illustrated by Figure 3.1. In this figure, 4-QAM and 16-QAM curves have been investigated. The total number of user can be denoted as *K*, which is considered as 1 and *N* represents the number of active user which will be allowed for communicating within the system can also be considered as 1. Since only one user existing within the system, selection method had not been considered to determine the optimum channel gains. As it can be seen from the figure that 4-QAM yields better performance as it contains fewer errors when compared with 16-QAM.

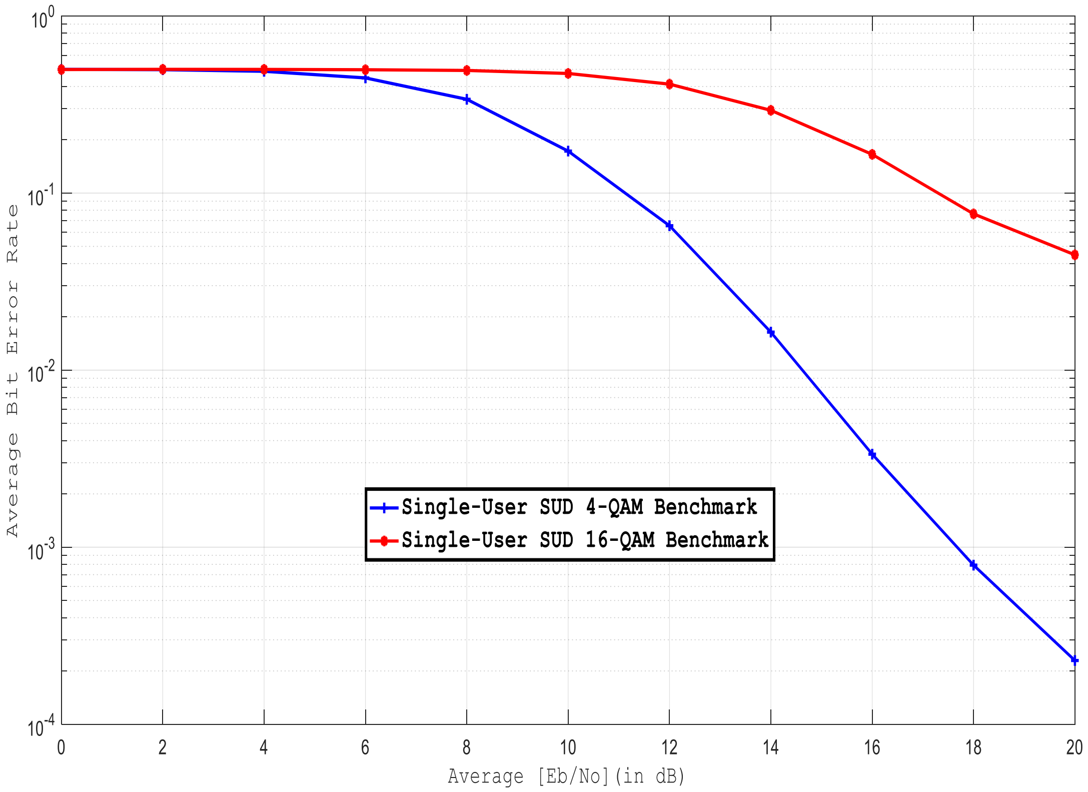

Figure 3.1: BER Performance of Single-User with Using Single-User Detection Technique, (*K*=1, *N*=1).

3.2.2 BER versus SNR Performance Estimation for MU-SUD System

The second scenario for the current study could be indicated as testing the performance of single user detector in multiuser environment. In this scenario, same frequency/time resource is shared among the users by using SUD. It is assumed that single user detector cannot detect all signals at the same time thus this case will cause Co Channel Interference (CCI).

In this case, 10 users are existing so that *K*=10. Moreover, the active users (*N*) which appointed for the scenario can be expressed as *N*= 2, 4, 8. To be more accurate; out of 10 users, two active users, four active users and lastly eight active users will be selected by considering the channel quality and tested independently to create an opportunity for observing various multiuser scenarios. It can be specified that all users' channel gains are calculated and will be ranked by descending order. Then, selected active users with high level of channel quality are allowed for utilizing the same bandwidth.

After the decision process of active users, SUD technique (which previously shown in Section 2.3.2) has been employed to detect all active user signals. The level of CCI in a Multi-User environment is expected to be high so that the Single-User detector perceives the CCI as an additional noise. Therefore, CCI will reach to the optimum level with addition of peak noise which in turn will decrease the quality of communication significantly.

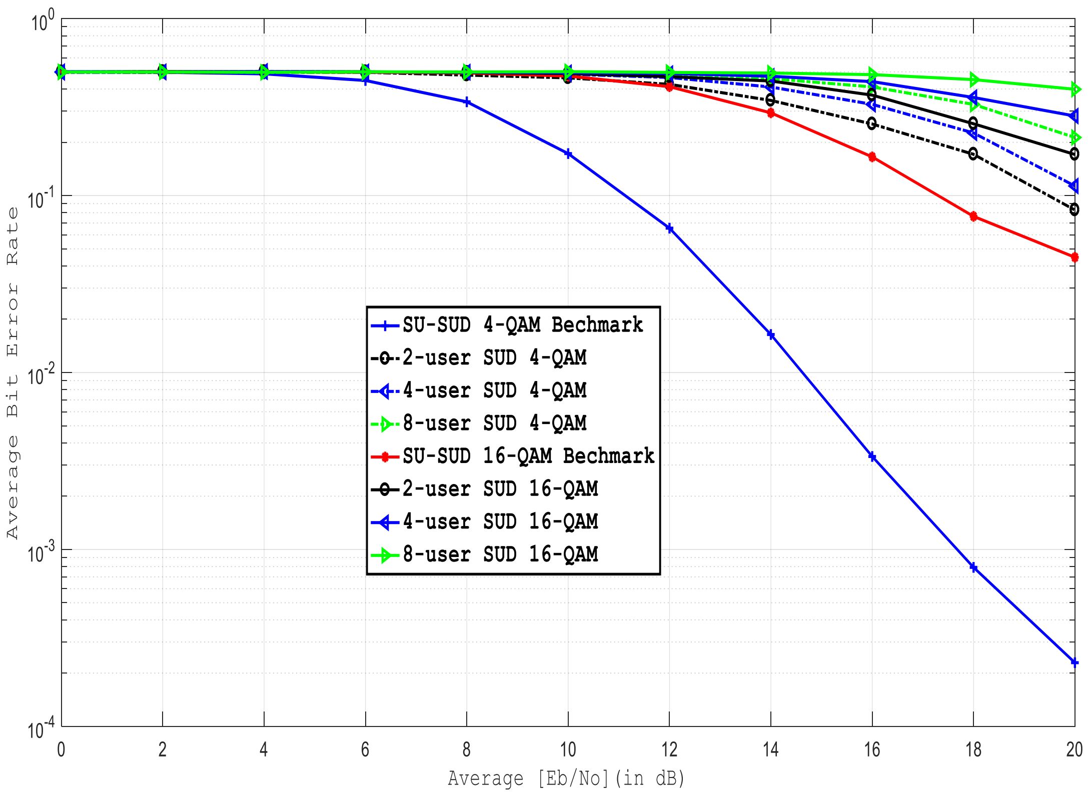

Figure 3.2: BER Performance of Multi-User with Using Single-User Detection Technique and Compared with Benchmark, (K = 10 and N= 2, 4, 8).

As seen Figure 3.2, Multi-User SUD system BER performance had compared with performance of Single-User SUD by evaluating BER performances. Results showed that high level of CCI effects in Multi-User SUD system can be seen from the given figure with compared benchmark (SU-SUD). Due to the reason of low BER in Multi-User SUD systems, MUD technique is required to deployed for the detecting all user signal simultaneously. The next section of the study will provide Multi-User performance with MUD technique.

3.2.3 BER versus SNR Performance Estimation for MU-MUD System

In the third scenario, independently generated signals for each user can be transformed as a matrix form (as shown Equation (2.12)) where each row index of matrix belongs to a user. Moreover, Multi-User Detection (MUD) technique can be implemented as in matrix form as shown in Section 2.4.3. In this case, a simulation will be carried to monitor the performance of system for active multiple users that are sharing same medium by using MUD.

MUD method provides parallel data detection scheme and thus all users' signal can be detected simultaneously. In multiuser environment, instead of considering other users' signal as CCI which existing in MU-SUD systems; it can be distinguished as users' signal by evaluating all signals in a matrix form when MUD is considered. Thus, unacceptable level of CCI would be avoided by using the MUD which in turn leads low BER performance.

As previously mentioned in MU-SUD simulation, same approach has been executed to observe different scenarios such as 2, 4 and 8 active users. It is vital to mentioned that these active users in the system are assessed with the light of the CSI feedback of 10 users. Also, the number of active users and all users can be identified as *N*=2, *N*=4 and *N*=8 out of *K*=10 users.

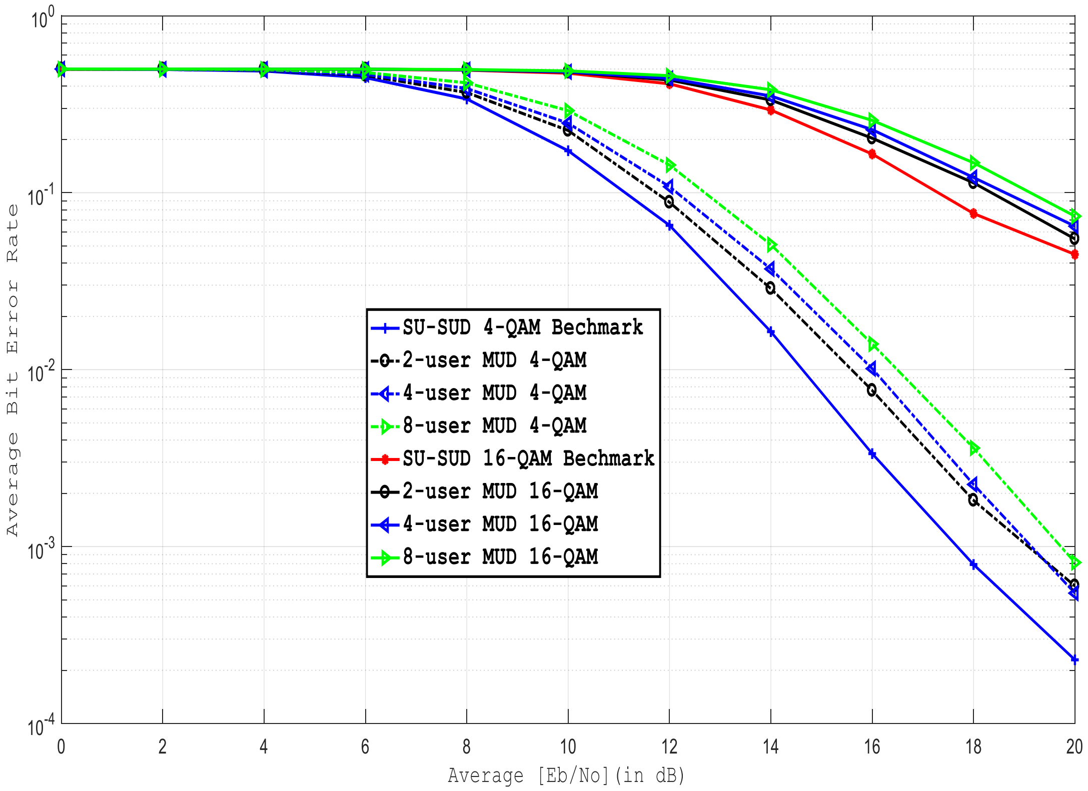

Figure 3.3: BER Performance of Multi-User with Using Multi-User Detection Technique and Compared with Benchmark, (*K* = 10 And *N*= 2, 4, 8).

Multi-User with MUD performance results were portrayed in forms of BER and SNR which demonstrated in Figure 3.3. The performance for both MU-SUD and MU-MUD should be compared with SU-SUD benchmark performance to observe differences between them.

Moreover, it can be clearly shown from the figure that MU-MUD curves very close to SU-SUD curve for all *N* values. Besides of this, it can be stated that BER performance gives worse result when the number of active multiple users increased from 2 to 8. Results have shown that MU-MUD have been increased the communication quality in Multi-User environment when compared MU-SUD results. Furthermore, by relying the results which shown in Figure 3.3 it can be clarified that MU-MUD performance curves are very close to the benchmark SU-SUD curve, which implies that CCI have only little effect on Multi-User signals thus quality of communication could be increased.

Chapter 4

CONCLUSION AND FUTURE WORK

This Chapter will summarize the work being done and will give detail information about future work by developing the current study. Further, importance of the current study for the future promises about MUD techniques will be stated.

4.1 Conclusion

Due to the increasing demand in the number of connections towards the IMT-A 5G systems, researchers are focusing on improvements that will improve both performance and capacity of the existing systems. Since the 5G is said to be based on OFDMA due to its competitive bandwidth efficiency just as the 4G, many researchers are concentrating on higher capacity and better performing OFDM based systems. Therefore, the proposed work has adopted the DVB-T system for a 2-way video communication system model for 5G. In conformance with the literature, the satisfactory BER performance in the proposed work is taken as 10^{-3}.

Due to the densification of the base stations, the Small Cell (SmC) architecture for IMT-A 5G will be Co Channel Interference (CCI) limited. Therefore, the CCI system performance of the DVB-T system over multipath fading channel needs to further improve to satisfy the target needs. It has been shown in the literature that Multi-User Detection (MUD) systems perform much better compared with the Single-User Detection (SUD) systems. This is due to the fact that in SUD, the CCI is handled as severe interference source whereas in MUD, the CCI is dissolved into useful signal source and detected along with the desired users signal by the detector.

In the current work, the video communication performance of DVB-T system adopted to IMT-A 5G systems employing SUD and MUD has been tested over flat-fading multipath communication channel by computer simulations using MATLAB. Three different scenarios are tested, SU-SUD, MU-SUD and MU-MUD. In the SU-SUD scenario there is only one active user in the system and a SUD is used to detect the signal at the channel output. In the MU-SUD scenario, there are multiple active users in the system but SUD is employed at the receiver, seeing the undesired users signals as CCI. In the MU-MUD scenario, there are many active users in the system and MUD is employed at the receiver. The BER versus SNR performance of these systems are compared by simulations.

In the SU-SUD scenario, the system performance is tested and taken as the benchmark to compare with the other 2 scenarios. The SU-SUD system performance has been shown to be unacceptably poorer compared with the SU-SUD system for both 4-QAM and 16-QAM modulation techniques. The MU-MUD on the other hand has shown acceptable performance which is slightly lower than the SU-SUD system for 4-QAM modulation. For 16-QAM modulation, however, the system performance is again unacceptably poor compared with the SU-SUD. Therefore, further improvement in performance will be needed if MU-MUD employing 16-QAM needs to be used in this scenario since high level of CCI degrades communications quality.

To observe different multiuser scenarios various numbers of active users are also considered. It has also been shown that increasing number of active users diminishes the BER vs SNR performance for 2, 4 and 8 active users.

The number of QAM constellations was also shown to influence the system performance due to the changing Euclidean distance. The 4-QAM modulation scheme has shown satisfactory performance in SU-SUD and MU-MUD cases whereas the 16-QAM performance did not meet the target requirement in performance.

4.2 Future Work

It is believed that to provide requirements towards IMT-2020, studies on IMT-2020 show that Multi-User MIMO-OFDM transmission scheme will take an important place in further technologies. It can be mentioned that the current study will be able to shed some light for the future work in some cases.

To advance understanding towards to the significance of the study specifications of IMT-2020 should be viewed. Recently, IMT- 2020 had advised a promising solution which is based on the usage of Multi-User environment that can be characterized as beam-forming. In such systems, undesired interference among users can be mitigated through beam-forming technique. Moreover, each user beam can be set separately by relying to the measurements of CSI. While CSI is important for such systems, it could be emphasized that presented MUD mechanism will take an important role for detection the CSI correctly as well as simultaneously for all users.

Another promising solution can be stated as power allocation strategy. The idea regarding power allocation strategy primarily focuses that more power allocation can be assigned to the users individually and independently particularly for those who are having poor channels [34]. In presented study, channel norms for all users have been calculated individually and sorted via descending order by considering the channel quality strength. It should be mentioned that the existing power has divided among users equally. It could be stated that to perform individual power allocation among active users as signaled in [34], it can be suggested that available power can be divided by considering the quality of channel gains instead of "user selection" method and MUD technique can be used.

For the future related studies, spectral efficiency can be discussed for those different three cases. The system capacity in terms of spectral efficiency for the Multi-User Detection case should give best result with good BER performance. For this reason, spectral efficiency performances will be investigated as future work.

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