Performance Analysis of UFMC in Massive MIMO System Under Channel Uncertainty

Melat Tefera Chiquala

A Thesis Submitted to

Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of

Master's in Electronics and Communication Engineering

(Specialization in Communication Engineering)

Office of Graduate Studies

Adama Science and Technology University

June, 2022

Adama, Ethiopia

Performance Analysis of UFMC in Massive MIMO System Under Channel Uncertainty

Melat Tefera Chiquala

Major Advisor: Dr. Ram Sewak Singh

Co Advisor: Prof. Balachandran R.

A Thesis Submitted to

Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electronics and Communication Engineering (Communication Engineering)

Office of Graduate Studies

Adama Science and Technology University

June, 2022

Adama, Ethiopia

APPROVAL PAGE OF M.SC THESIS

We, the advisors of the thesis entitled "Performance Analysis of UFMC in Massive MIMO System Under Channel Uncertainty" and developed by Melat Tefera Chiquala, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

______________	____________	_____________
Major Advisor	Signature	Date
______________	____________	_____________
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Melat Tefera Chiquala have read and evaluated the thesis entitled "Performance Analysis of UFMC in Massive MIMO System Under Channel Uncertainty" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electronics and Communication Engineering.

______________	____________	_____________
Chairperson	Signature	Date
______________	____________	_____________
Internal Examiner	Signature	Date
______________	____________	_____________
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

______________	____________	_____________
Department Head	Signature	Date
______________	____________	_____________
School Dean	Signature	Date
______________	____________	_____________
Office of Postgraduate Studies, Dean	Signature	Date

DECLARATION

I declare that this Master Thesis entitled "Performance Analysis of UFMC in Massive MIMO System Under Channel Uncertainty" is my own work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Melat Tefera	__________________	__________________
Name of student	Signature	Date

RECOMMENDATION

We, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled “Performance Analysis of UFMC in Massive MIMO System Under Channel Uncertainty” prepared under our guidance by Melat Tefera submitted in partial fulfillment of the requirements for the degree of Master of Science in Electronics and Communication Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

____________	____________	______________
Advisor	Signature	Date
____________	____________	______________
Co-Advisor	Signature	Date

ACKNOWLEDGMENT

First and foremost, I am thankful to God, for helping me to successfully complete this work. And I would like to thank my advisor, Dr. Ram Sewak, and co-advisor Prof. Balachandran R., for their direction and unwavering support during my thesis work I appreciate their patience and encouragement, especially at a time when I needed it the most.

In addition, I'd like to express my gratitude to all of my classmates and laboratory staff members for encouraging me, providing an open lab room for discussion when I have a meeting with my advisor, providing a very friendly working environment, and making me feel very welcome during my thesis research.

Finally, I am grateful to my mother, who has always allowed me to go my own way and has made me feel free to do whatever I choose.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBBREVIATIONS

5G	Fifth Generation
BER	Bit Error Rate
BSs	Base Stations
CP	Cyclic Prefix
CSI	Channel State Information
DL	Downlink
DSL	Digital Subscriber Line
EE	Energy efficiency
FBMC	Filter Bank Multicarrier
GFDM	Generalized Frequency Division Multiplexing
ISI	Inter-Symbol Interference
LTE	Long Term Evolution
MATLAB	Matrix Laboratory
MC	Multi-Carrier
MIMO	Multiple Input Multiple Output
MISO	Multi-Input Single-Output
MMSE	Minimal Mean Square Error
MU-MIMO	Multi User Multiple Input and Multiple Output
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OOBE	Out-Of-Band Emission
OQAM	Offset Quadrature Amplitude Modulation
PAPR	Peak to Average Power Ratio
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service

SE	Spectral Efficiency
SIMO	Single-Input Multi-Output
SISO	Single-Input Single-Output
SNR	Signal to Noise Ratio
UEs	User Equipment's
UFMC	Universal Filtered Multicarrier
UL	Uplink
WiMAX	Worldwide interoperability for Microwave Access
WLAN	Wireless Local Area Network

ABSTRACT

Multiple-Input Multiple-Output (MIMO) is a radio antenna system that uses multiple antennas at both the transmitter and receiver to improve the radio link's quality, throughput, and capacity. MIMO uses techniques known as spatial diversity and spatial multiplexing to transmit independent and separately encoded data signals, known as "streams", reusing the same time period and frequency resource. Massive MIMO refers to the use of a high number of antennas on a base station in order to serve many active users in the same time frequency block. The capacity of massive MIMO to increase throughput and spectral efficiency has made it a crucial technology for emerging wireless standards. Orthogonal Frequency Division Multiplexing (OFDM) have been the most attractive one for the development of wireless communication system like 4G in the advantages like ease of implementation, immunity to interference, high data rate etc. In this thesis, we provide the analysis and comparison of the candidate waveforms, Filter Bank Multicarrier (FBMC) and Universal-filtered multicarrier (UFMC). FBMC introduces an overhead in overlapping symbols in the filter bank in the time domain. Universal filtered multicarrier (UFMC) inherits the robustness of FBMC and simplicity of OFDM. In this thesis, performance comparison in terms of spectral efficiency, power spectral density (PSD), peak to average power ratio (PAPR) and Bit error rate (BER) presented. The result demonstrates the benefits and drawbacks of each modulation scheme. Furthermore, we can see from the simulation results that UFMC has a lower BER value at low SNR values, indicating a high receiver sensitivity that is conducive to better system performance. Due to long filtering length in FBMC it is insensitive to multiuser interference to support different use cases with in same bands. UFMC, reveals to be most promising which close to OFDM with advantage of better out-of-band (OOB) emission. Finally, in order to improve spectral efficiency, the UFMC waveform is well suited as a modulation and demodulation technique for massive multiple-input multiple-output (M-MIMO) technology.

Keywords: *PSD, Spectral efficiency, BER, PAPR, OFDM, FBMC, UFMC, Massive MIMO*

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Wireless communication is a broad term that incorporates all procedures and forms of connecting and communicating between two or more devices using a wireless signal through wireless communication technologies and devices. When we connect to internet, the speed of your internet depends upon the signal strength that has been shown in alphabets like 2G, 3G, 4G, 5G etc. right next to the signal bar on your home screen. Each Generation is defined as a set of telephone network standard, which detail the technological implementation of a particular mobile phone system. This evolution journey was started from 1G and it is still continuing to 5G.

Each of the Generations has standards that must be met to officially use the G terminology. There are institutions in charge of standardizing each generation of mobile technology. Each generation has requirements that specify things like throughput, delay, etc. that need to be met to be considered part of that generation. Each generation built upon the research and development which happened since the last generation. In 1G, the voice signal was modulated using the frequency modulation (FM) technology. Users were allotted a frequency for transmission to a base station (uplink) and a frequency for reception from the base station during a call (downlink) (Banelli et al., 2014).

1G was not used to identify wireless technology until 2G, or the second generation, was released. That was a major jump in the technology when the wireless networks went from analog to digital. Second generation (2G) system emerged in the 1990s which provides the digital transmission and services like SMS, internal roaming, conference calls, call hold and billing based on services e.g., charges based on long distance calls and real time billing. Time-division multiple access (TDMA) was the original proposal for 2G systems, in which each assigned bandwidth was slotted in time so that users may use the same spectrum. Because large guard periods are required to mitigate the multipath impact, TDMA is inefficient when dealing with high data rate channels. To eliminate inter-carrier interference, FDMA uses extra bandwidth for guardians. Code Division Multiple Access (CDMA) was introduced as part of the 2G standard (CDMA). For the same transmitted power, CDMA spreads the data bandwidth evenly. The use of CDMA enhanced system capacity and data throughput, making it more efficient in handling multipath channels. The low data rates delivered by 2G systems were insufficient to meet the demand for mobile internet access. As a result, there is a demand for third generation (3G). When 3G was introduced, it provided greater data speeds of up to 2 Megabits per second (Mbps), which was the world's first mobile broadband. As a result, new services such as web surfing, email, movie downloading, photo sharing, and other smart phone technologies are being introduced. The fourth generation (4G) of cellular networks was introduced around 2010 by succeeding 3G. 4G is a technology which provide high speed, better spectral efficiency, high bandwidth and high capacity to users by improving security and lower the cost of voice and data services, multimedia and internet-protocol based services (Schaich et al., n.d.).

Potential and current applications include video conferencing, HD TV, voice over IP, gaming services, 3D television and cloud computing. The max speed of a 4G network is 100Mbps or 1Gbps for low mobility communication like when stationary or walking, latency reduced from around 300ms to less than 100ms, and significantly lower congestion. 4G is not the same as 4G LTE which is very close to meeting the criteria of the standards. Newer generations of phones are usually designed to be backward-compatible, so a 4G phone can communicate through a 3G or even 2G network.

All carriers seem to agree that OFDM is one of the chief indicators that a service can be legitimately marketed as being 4G. OFDM is a type of digital modulation in which a signal is split into several narrowband channels at different frequencies. The downlink modulation approach for the 4G/LTE system is based on the Orthogonal Frequency Division Multiplexing (OFDM) waveform, and the uplink modulation scheme is based on the single-carrier frequency division multiple access (SC-FDMA) technique. For 3G systems, Phase-shift keying was employed, which is a more spectral efficient modulation strategy, however for 4G systems, Quadrature Amplitude Modulation (QAM) is used.

5G is a generation currently under development, that's intended to improve on 4G. 5G provides faster data rates, higher connection capacity, much lower latency, better battery consumption, better coverage among other improvements. The maximum speed of 5G is as fast as 35.46Gbps, which exceeds the 4G system about 35times. The enable technologies to look out for 5G are Massive MIMO, Millimeter Wave Mobile Communications, small cells, Li-Fi etc. All the new technologies from the previous decade could be used to give 10Gbps to a user, with an unseen low latency and allow connections for at least 100 billion devices.

Because of the associated advantages of robustness against multipath fading, which divides the channel into narrow flat fading channels, efficient one-tap frequency domain equalization enabled by the use of Cyclic Prefix (CP), ease of implementation, OFDM is a well-known multicarrier scheme. Even while it has numerous benefits, it also has some disadvantages. The rectangular pulse shape causes high out-of-band interference, the cyclic prefix insertion causes spectral efficiency loss, and strict time and frequency synchronization is required to prevent subcarrier orthogonality, which ensures a low level of intra and inter-cell interference. Furthermore, OFDM signals have a high peak-to-average power ratio (PAPR), which has a significant impact on system energy efficiency (Farhang-Boroujeny, 2011).

Several alternative modulation candidate schemes, such as Filter Bank Multicarrier modulation (FBMC), Universal Filter Multicarrier modulation (UFMC), filtered OFDM (f-OFDM), Generalized Frequency Division Multiplexing (GFDM), and others, have been studied in many literatures to overcome these limitations.

1.2 Statement of Problem

The basic essential criteria for 5G systems are network capacity, data rate, latency, coverage, spectral efficiency, reliability, peak to average power ratio, energy efficiency of as well as cost. Even though OFDM is the most widely used multicarrier technique in wireless standards, it has some drawbacks, such as the use of cyclic-prefix (CP), which reduces the waveform's spectral efficiency, large side lobes, which limits spectrum utilization, and a high peak-to-average power ratio (PAPR), which reduces the system's performance. As a result, OFDM is unlikely to be used in a 5G mobile communication system. Other waveform possibilities for the 5G physical layer have been researched to alleviate the difficulties of OFDM. As a result, new technologies such as the Filter Bank Multi Carrier (FBMC) and the Universal Filtered Multi Carrier (UFMC) have evolved. However, FBMC is not the best option because it uses a long filter length, which affects symbol decoding time, and it has a complex MIMO receiver structure, making it unsuitable for burst transmissions or time-sensitive applications. UFMC, like FBMC, has better subcarrier separation and offers less complexity than OFDM. In this paper, we examined how a large MIMO system with UFMC performs in the face of channel uncertainty.

1.3 Objective

1.3.1 General Objective

The main aim of this thesis work is to compare the performance of UFMC with existing methods for the evaluation of Massive MIMO system under channel uncertainty.

1.3.2 Specific Objectives

The following specific tasks help to achieve the above overall goal:

1. Detail review and analysis of the cons and pros of OFDM and FBMC.
2. Studying the behavior and the challenges faced on massive MIMO system.
3. Comparing the parameters PAPR, BER, Power Spectral Density and Spectral Efficiency of UFMC, OFDM and FBMC.
4. Determining the modulation type and filtering technique which is best for UFMC.
5. Evaluating the performance of Massive MIMO system under channel uncertainty.

1.4 Methodology

To accomplish the proposed work general and specific objectives of the design, the following procedural methods have been followed.

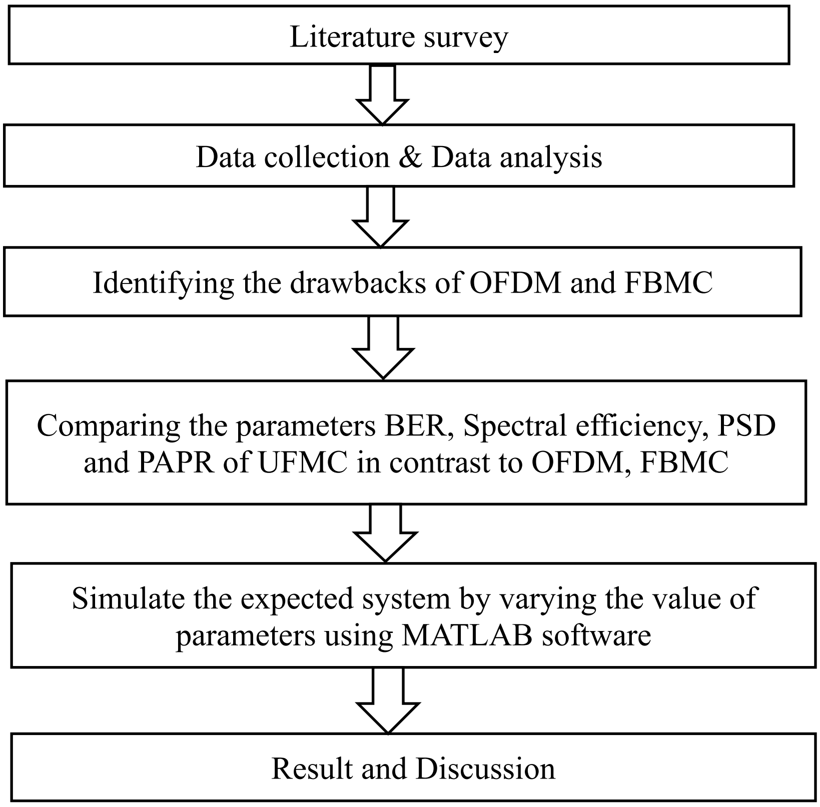

Figure 1.1: Flow chart of the system

1.5 Significance of the Study

The modulation schemes used for the future 5G networks should have a significant impact on the whole performance and will play a major role in determining the performance and complexity of communication systems; with the development needs of high speed, low latency, frequency-offset robustness and better spectrum efficiency.

UFMC collects the advantages of OFDM and FBMC. UFMC uses sub band filtering; these sub bands consist of number of sub-carriers. Out of band emission in UFMC is much lesser than OFDM because of the filters used. Sub band filtering reduces the filter lengths in UFMC which makes it suitable for short data transmission. Because of the QAM modulation employed at the transmitter, UFMC is compatible with MIMO methods. For both perfect and non-perfect synchronization between user equipment (UEs) and base stations, UFMC surpasses OFDM (BSs).

1.6 Thesis Organization

This thesis organizes into the following five chapters.

Chapter 1: Background of network generation from 1G to 5G and the modulation techniques used in each generation, statement of the problems, general and specific objectives of the thesis, methodology and significance of the study.

Chapter 2: presents the literature review of the subject matter and it provides an overview of the problem's background. It refers to what has already been researched by others and has relevance to the present day.

In chapter 3, describes the materials and methods followed in this research thesis.

In chapter 4, presents the proposed results and discussions.

In chapter 5, Conclusion and Recommendation.

Finally, References and Appendix

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Related Works

Performance Analysis of UFMC and its Comparison with CP-OFDM presented in (Sadhana .T and Soundharya .V, 2018). The comparison parameters power spectral density (PSD) and Peak to Average Power Ratio are used in this work (PAPR). They discovered that the PSD result of UFMC beats that of OFDM, and that the PAPR variation of the two is nearly identical. UFMC's BER performance was likewise successful. Because it was simulated using the additive white Gaussian noise (AWGN) channel, these limitations limit the paper.

Spectral Efficiency Analysis in Massive MIMO using FBMC-OQAM Modulation presented in (Jose et al., 2018). In this paper, the potential of Filter Bank Multicarrier (FBMC) modulation as an alternative to be used in the future 5G wireless networks in which Massive Multiple-Input Multiple-Output (MIMO) will be deployed. The study compares orthogonal frequency division multiplexing (OFDM) with FBMC. The data throughput of a SISO system was taken from simulation results and checked by measurements to offer a method to analyze the SE for the MM system uplink in this paper. The performance of FBMC and OFDM modulations in a more realistic setting was studied using this technique. However, because to the lengthy in filter, FBMC has a high level of complexity, which reduces system performance.

Compressive overview of the most promising modulation and multiple access schemes for 5G was present in (Cai et al., 2018). In this paper Orthogonal Multiple access (OMA) and Non-Orthogonal Multiple access (NOMA) schemes discussed. They are attempting to identify modulation schemes that have the potential to be used in OMA. The performance of a few modulation schemes was compared in terms of out-of-band leakage and bit-error rate. The authors are also focused on various types of NOMA candidates, including power-domain NOMA, code-domain NOMA, and NOMA multiplexing in multiple domains. Finally, they suggested a new modulation schemes with less out-of-band leakage for orthogonal MA of 5G network. They also got more interest on NOMA for providing enhanced throughput and massive connectivity with improved spectral efficiency. The performance comparison was only bounded on two metrics.

Performance Evaluation of QAM for Improvement of BER by (Singh et al., 2019). This paper presented the performance evaluation of the M-ary quadrature amplitude modulation (M-QAM). BER performance is evaluated on operation of the binary coding, The Gray coding, Pulse shaping in raised cosine filter and Error correction using convolution codes. Simulation results shows the BER and SNR of M-QAM (M = 16, 64, 256 and 1024) for oversampling factor 1, 2, 3, 4 and 5. BER and SNR is related to spectral efficiency (SE) i.e., SE is the optimize use of spectrum for highest quantity of information can be transmitted with the least transmission errors. SNR and BER will increase as order of QAM increases. Improvement in BER shows that the increment in the number of errors.

BER Analysis of Filter Bank Multicarrier for 5G Wireless Communications by (Satish Kanapala, 2019). In this paper, they proposed OQAM based FBMC with reduced bit error rate characteristics as close as to theoretical results with moderate complexity. It is simulated with MATLAB Software, and the simulation results show the better BER with respect to SNR as compared with the traditional methods. They noticed that the simulation results are very nearer to the theoretical results. The proposed FBMC with OQAM gives the improved bit error rate when compared with the simulation results of cyclic prefix OFDM and coded FBMC-OQAM.

PAPR Reduction in UFMC for 5G Cellular Systems by (Al-Rayif et al., 2020). To alleviate PAPR in UFMC systems, this work provides a comparative probabilistic PAPR reduction strategy dubbed the decomposed selective mapping approach. Prior to the inverse fast Fourier transform (IFFT), the complex symbol is decomposed into real and imaginary parts, and each part is converted to a number of different phase vectors. The IFFT copy is chosen for transmission because it has the lowest PAPR. The proposed approach can greatly improve the performance of the UFMC system in terms of PAPR reduction, according to results acquired through theoretical analysis and simulations. It also keeps the OOB emission with candidate bit error rate and error vector magnitude performance.

Design and Research on FBMC-OQAM Multicarrier Technology for 5G by (Ling Yao,2020). This paper Aimed at the low frequency utilization of OFDM due to adding cyclic prefix, a

FBMC - OQAM system design based on frequency sampling prototype filter is proposed. In this paper, the performance difference between FBMC-OQAM and OFDM is studied by building the system model and the effect of the overlap factor of the prototype filter on the performance of multi-carrier technology in FBMC-OQAM system is also studied. It is verified that the system has high frequency utilization and good out-band suppression ability and it has good application value in 5G system.

2.2 Fundamentals of 5G systems

The 5G system is primarily aimed at increasing data rate, availability and reducing latency. Mobile networking is a wireless technology that can provide radio transmission to provide voice and data networking. Mobile data traffic is now rapidly generated, with Smartphone's, tablets and various data traffic devices becoming quite successful. There are three key techniques for 5G communications from the perspective of system capacity. That is, the massive MIMO technique adopted to improve system SE; mm-wave spectral resources are employed to expand system bandwidth; and multi-layer and ultra-dense networks are deployed to increase geographic spectral reuse. The systems employing massive antenna arrays to serve multiple users are massive MIMO communication systems. Massive MIMO systems are capable of combating the severe fading of mm-wave signals, providing the wireless backhaul and suppressing interference in multi-layer and denser networks. Some of the significant advantages of 5G are:

Data rate: 5G network would provide data rate up to 10Gbps, which is almost a hundred times better than 4G networks.

Latency: 5G network provides latency as low as 1ms compared to 10ms latency provided by 4G networks.

Efficient Signaling: 5G networks provide efficient signaling for IOT connectivity and M2M communication.

User Experience: 5G enhances augmented reality, virtual reality, and artificial intelligence.

Spectral Efficiency: 5G would provide ten times more spectral and network efficiency compared to 4G networks.

Energy efficiency: 5G networks provide 90 % more efficient network energy usage compared to 4G networks.

Ubiquitous Connection: 5G provides huge broadcasting data, which can support more than 65,000 connections, which are a hundred times more than 4G networks.

Battery life: 5G provides almost ten years of battery life for low powered IOT device.

2.2.1 Key Enabling Technologies for 5G

To make 5G and beyond networks in reality, many advanced ideas have been proposed and analyzed in recent years. The major key enabling technologies that have been considered for 5G system include millimeter waves, small cells, beamforming, device-centric architecture, full-duplex technology, massive MIMO, Terahertz wave, and visible light spectrum as shown in Figure below.

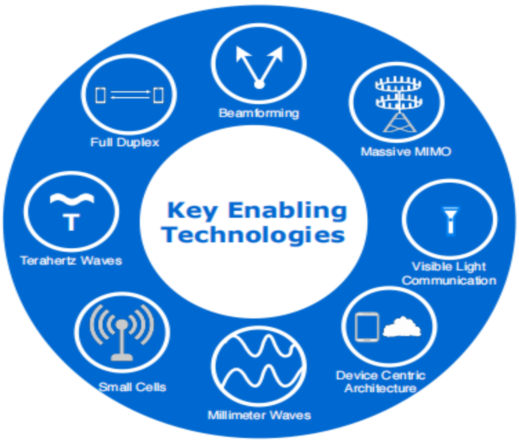

Figure 2.1: key Enabling Technologies for 5G (E, 2018)

2.3 Millimetre Waves

Generally, a frequency below 6 GHz is used for cellular communication, and frequency above that is mostly used for other services like medical imaging, microwave remote sensing, amateur radio, terahertz computing, and radio astronomy. The massive increase in data traffic has made the radio frequency spectrum congested. The result is that there is limited bandwidth for a user, causing a slower and unreliable connection. One way to solve this problem is by using frequency above 6 GHz for wireless communication. The frequency above 6 GHz has never been used for wireless communication, and there has been a lot of research going on with broadcasting millimetre waves. Millimetre waves are frequency between 30 GHz to 300 GHz, and it is called millimetre waves because its length varies from 1 to 10 mm compared to the radio waves that are used in the current mobile communication system, which measure tens of centimetres in length. Millimetre waves can provide bandwidth ten times more than that of the entire 4G cellular band. These high-frequency waves are used in some satellite application, but it has never been used for mobile broadband. Since millimetre has a lower wavelength, they are not suitable for long-range applications.

Another problem with millimetre waves is that they cannot penetrate buildings and obstacles, and they tend to get absorbed by rain (D. Wu et al., 2015).

2.4 Sub-Millimetre or Terahertz Band

The frequency band between 300 GHz to 3 THz is known as the Terahertz band. Although this idea is relatively new, research in this area can be worthwhile for the wireless communication industry. Other than higher spectrum THz band has the advantages of interference friendly deployment, enhanced security, low power consumption, a front-haul boost for the wireless network, scalability, small antennas size, availability of Greenfield spectrum and focused beams. THz technology would be beneficial for applications such as imaging, spectroscopy, holographic tele-presence, industry 4.0, and massive scale communications. There are several challenges and new areas of research in THz band deployments such as complex antenna design to support higher antenna gain, access point specification and deployment, complex circuit design, high propagation loss and complex mobility management (Song et al., 2016).

2.5 Full Duplex Technology

Full duplex refers to the simultaneous transmission and reception over the same frequency band and at the same time. Wireless transmission and reception are not done at the same frequency bands to avoid interference. Any bidirectional system has to separate the uplink and downlink channel using time or frequency domain to get orthogonal non-interfering signals. 5G networks will use full-duplex for the transmission of signals to potentially double the network capacity and is beneficial for higher layers (e.g., MAC layer). One of the limitation of full-duplex technology is that it increases signal interference thought pesky echo (D. Wu et al., 2015).

2.6 Beamforming

Beam forming is the ability of the base station to adapt the radiation pattern of the antenna Beam forming helps the base station to find a suitable route to deliver data to the user and it also reduces interference with nearby users along the route. Beamforming increases the spectrum efficiency for the massive MIMO systems and for millimetre waves, it helps in boosting data rate. In massive MIMO systems, the base station can send data to the user from various paths, and beamforming here choreographs the packet movement and arrival time to allow more users to send data simultaneously. Since the millimetre waves cannot penetrate through obstacles and do not propagate to longer distances due to a shorter wavelength, beamforming here helps to send concentrated beams towards the users. Thus, beamforming helps a user to receive a strong signal without interference with other users.

2.7 Multiple-Input Multiple-Output (MIMO) Technology

Multiple input multiple output (MIMO) is a technique for increasing the capacity of a wireless connection without the need for more spectrum. MIMO techniques can increase mobile communication in two ways: by raising overall data rates and by increasing the communication link's reliability. Receive diversity, transmit diversity, beamforming, and spatial multiplexing are the four major categories of MIMO algorithms utilized in LTE standards. Distribute redundant data across multiple antennas in Transmit Diversity and Beamforming. As a result, these techniques do not increase the possible data rates; rather, they strengthen the communication link. However, in spatial multiplexing, the system sends out independent data through different antennas. Figure 2.2 shows the basics antenna configurations; SISO, SIMO, MISO and MIMO systems. MIMO is becoming more popular as a wireless technique that can deliver significant performance advantages over classic single-input single-output systems.

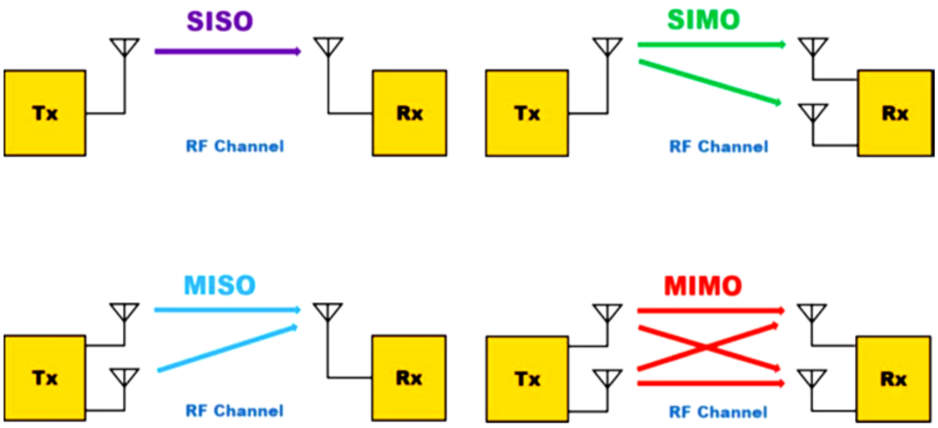

Figure 2.2: SISO, SIMO, MISO, and MIMO systems (Agbotiname Lucky Imoize, 2021)

Before the introduction of MIMO, single-input-single-output systems were mostly used, which had very low throughput and could not support a large number of users with high reliability. To accommodate this massive user demand, various new MIMO technology like single-user MIMO (SU-MIMO, multi-user MIMO (MU-MIMO) and network MIMO were developed. However, these new technologies are also not enough to accommodate the ever-increasing demands. The wireless users have increased exponentially in the last few years, and these users generate trillions of data that must be handled efficiently with more reliability. The current MIMO technologies associated with 4G/LTE network is unable to handle the huge data traffic with more speed and reliability. Thus, the 5G network is considering massive MIMO technology as a potential technology to overcome the problem created by massive data traffic and users.

2.7.1 Point-to-Point MIMO

Point to Point MIMO is the simplest form of MIMO technologies, which require both the transmitter and receiver of a communication link installed with an array of antennas. Combination between frequency/time division multiplexing is used to serve different users in distinct time/frequency blocks. Therefore, throughput is increased without using more bandwidth or pumping higher power. The capacity of the link can be improved by simultaneous use of a large number of antennas at the transmitter and the receiver. There are three key factors that limit the Point-to-Point MIMO usefulness even with massive arrays at the link terminals. First, the propagation environment should support minimum base stations and terminal antennas' independent streams. In a real life this is difficult to achieve, mainly when compact arrays are used. Second, the terminal equipment is quite complex, and it requires independent RF chains per antenna and the use of advanced digital signal processing techniques to separate the data streams. Last, the spectral efficiency scales slowly with the minimum base station and terminal antennas near the cell edge, where ordinarily many of the terminals are located and where SNR is practically low due to sever path loss in the propagation paths (Alrashdi et al., 2020).

2.7.2 Multiuser MIMO (MU-MIMO)

The MU-MIMO system is a MIMO technology where multi-antenna BS serves multiple UE; each BS with multiple antennas can use the same frequency-time resources to serve a multiplicity of single antenna terminals that share the multiplexing gain. Cooperation between the antennas of the UE is possible in the case of the point-to-point MIMO; however, UEs in MU-MIMO cannot communicate with each other. Although the poor-quality channels can sometimes severely influence the throughput achieved by individual users. The impact of the propagation environment on MU-MIMO system is less than that of point-to-point MIMO due to the multi-user diversity. As a result, many communication standards such as 802.16 (WiMAX), 802.11 (Wi-Fi) and LTE have included MU-MIMO. The BS usually is equipped with only few numbers of antennas for most MIMO application. Thus, only modest improvement is brought to the spectral efficiency using the MIMO technology. The reasons that make multiuser MIMO better than Point to Point MIMO are its less sensitivity to the propagation environment and the sufficient of single antenna terminals. The sensitivity gives the system good performance even when line of sight conditions is present. However, Multiuser MIMO cannot be scalable because of the complexity of dirty paper coding and decoding grows exponentially and the time needed for training to acquire the channel state information (CSI) increases in proportion with the number of users and the BS antennas (Shreesh & Chopra, 2018).

2.7.3 Massive Multiple-Input Multiple-Output (M-MIMO)

In order to scale up the traditional MIMO, the massive MIMO concept, which is also known as Large-Scale MIMO (LS-MIMO) scheme often also associated with the terminologies of large-scale antenna systems, very large MIMO, very large MU-MIMO, full-dimensional MIMO, hyper MIMO, etc., was proposed by Marzetta. More explicitly, massive MIMO refers to the system that uses hundreds of antennas to simultaneously serve dozens of UEs. Massive MIMO is being considered as a potential candidate approach for next-generation wireless communications systems, with the goal of increasing both bandwidth efficiency and energy efficiency. Consequences of the powerful signal processing made possible by the huge number of antennas at the transmitter and/or receiver in order to improve link performance (Sun et al., 2021).

Massive MIMO is a radical departure from conventional MIMO technology, in which the number of antennas at the base station is dramatically expanded (by an order of magnitude or more over current MIMO systems) to reap even greater advantages. There is presently no standard specification for how many antennas a system must have to be labeled Massive MIMO, but systems with more than 16 antennas are commonly referred to as such. Massive MIMO is now gaining traction as a possible alternative for increasing capacity in multiuser networks. Massive MIMO envisions huge increases in spectral efficiency, energy efficiency and network interference reduction, all of which are critical to meeting the needs of a data-centric society where spectrum and energy are becoming increasingly valuable. In a Massive MIMO system, a base station uses M antennas to spatially multiplex K single antenna terminals, where K less than M. Multiplexing is accomplished using beam formation, also known as multiuser Precoding, which effectively creates transmitted signals that add up constructively where the terminals are placed and destructively practically everywhere else. The success of such a spatial multiplex in both uplink and downlink depends on the base station's knowledge of the propagation channel in both directions, which can be used to design effective downlink precoders and uplink detectors. (Chataut, 2020).

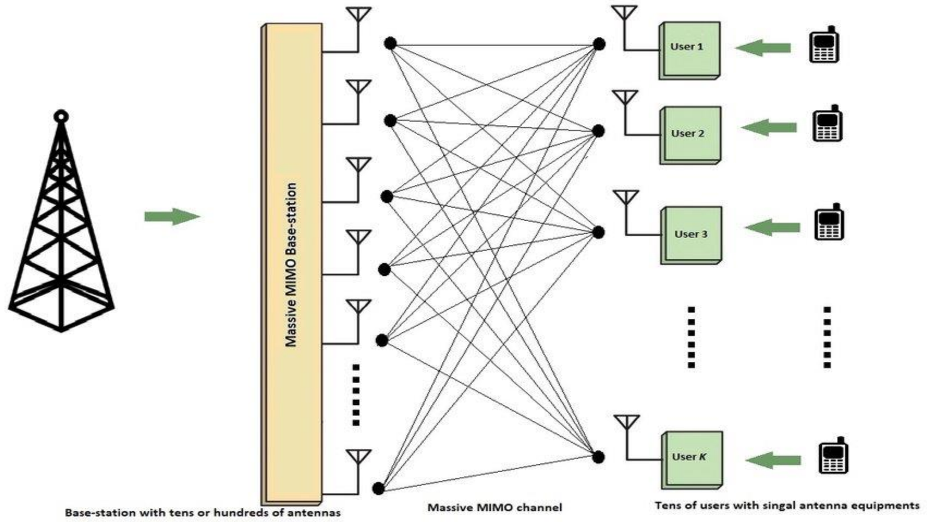

Figure 2.3: Massive MIMO System (E, 2018)

2.7.3.1 Benefits of Massive MIMO for 5G Technology

Massive MIMO is the most fascinating wireless access technology for delivering 5G system requirements. Some of the basic benefits of massive MIMO technology are Spectral efficiency, energy efficiency, high data rate, user tracking, less fading, low power consumption, robustness, reliability and low latency with enhanced security. The need for more reliable communications and the demand for wireless throughput will always increase. The capacity of the UL transmission under favorable propagation conditions is (DL transmission follows the same argument):

$$\mathrm{C_{sum}} = \log_2 \det\left([\mathrm{I_K}] + \rho_r[\mathrm{MD_\beta}]\right) = \sum_{k=1}^{K} \log_2\left(1 + \rho_r[\mathrm{MD_\beta}]\right) \quad (2.1)$$

When M and K are representing the array gain and multiplexing gain respectively. It is obvious that large K and M result in a very high energy and spectral efficiency. Hence, by increasing K and M, higher number of users can be served over the same frequency band without the need of increasing the transmit power of every terminal. Therefore, the throughput of every user increases. Moreover, the transmit power can be reduced 3dB by doubling the number of antennas in the BS without compromising the quality of service.

Favorable propagation conditions and Optimal processing at the BS are necessary to get the array and the multiplexing gain. These gains can also be achieved using linear processing with massive MIMO instead of the usual low dimensional point to point MIMO with very complicated processing schemes. In fact, when the number of BS antennas is increased to a very large number in massive MIMO, the channel becomes favorable because of the low of large numbers. Therefore, linear processing is considered almost optimal for massive MIMO also, the throughput can always be improved by increasing the number of users and the BS antennas (Nadeem et al., 2015).

2.7.3.2 Challenges Faced in Massive MIMO

Even though M-MIMO has several advantages, many issues has been still tackled. The most identified challenges of Massive MIMO are;

Pilot Contamination: is a condition that occurs when the precoding matrix adopted at a base station is correlated with the channel of users in other cells because of non-orthogonal pilots allocated to users. In massive MIMO systems, the base station estimates the channel response of the user terminal in its cell while user equipment in another cell communicates to the same pilot signal (interference). Since pilot contamination gives rise to coherent interference, it influences the achievable throughput.

Channel Estimation: For signal detection and decoding, massive MIMO relies on Channel State Information (CSI). It increases hardware and computational complexity due to more number of antennas (Björnson et al., 2020). Thus, low complexity and low overhead channel estimation algorithm are very desirable for massive MIMO systems.

Precoding: Although the precoding technique provides immense benefits to massive MIMO systems, it also increases the computational complexity of the overall system by adding extra computations. The computational complexity increases along with the number of antennas. Thus, low complex and efficient precoders are more practical to use for massive MIMO systems.

Signal Detection: In massive MIMO systems, due to a large number of antennas, the uplink signal detection becomes computationally complex and reduces the achievable throughput. Also, all the signals transmitted by users superimpose at the base station to create interference, which also contributes to the reduction of throughput and spectral efficiency.

2.8 Digital Modulation and Demodulation Techniques

Modulation is the process by which some characteristics of carrier signal like phase, angle, amplitude and frequency are varied according with modulating (message) signal characteristics using different modulation technique. The receiver then recovers the original signal through a reverse process called demodulation. That means the purpose of demodulation is to extract the original message signal from the received signal. The uses of different modulation techniques depend on whether the input is analog or digital. For a given digital data of finite bit sequence to be transmitted over a channel by a band pass filtered signal a mapping process known as digital modulation is required between the bit sequence and possible signals. The mapping rule is also important for proper demodulation and detection at the receiver. Different digital modulation techniques can be compared and identified with their bit error rate performance, less power consumption and better spectral efficiency. As the modulation order increases higher data rates are able to offer much faster data rates and higher levels of spectral efficiency for mobile wireless communication systems, this comes at a price. The higher order modulation schemes are considerably less resilient to noise and interference. The basic concept behind digital modulation is to identify efficient schemes taking M different symbols in a given digital alphabet and transforming them into wave forms that can successfully transmit the data over the transmission channel. In modern digital communications systems, the modem (i.e., modulate-demodulate) has the responsibility of converting the digital data to analog signals for transmission and from analog signals to digital data for the received signal (E, 2018).

Modulation involves changing the amplitude, frequency and/or the phase of the carrier wave traveling over the channel, and also modulation is the process by which some characteristics of carrier signal like phase, angle, amplitude and frequency are varied according with modulating (message) signal characteristics using different modulation technique. Digital modulation techniques are the fundamental building blocks of the physical interfaces of all digital communication systems. Techniques such as Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Differential Phase Shift Keying (DPSK) and Quadrature Amplitude Digital modulation techniques are the fundamental building blocks of the physical interfaces of all digital communication systems. The receiver then recovers the original signal through a reverse process called demodulation. That means the purpose of demodulation is to extract the original message signal from the received signal. The uses of different modulation techniques depend on whether the input is analog or digital. Different digital modulation techniques can be compared and identified with their bit error rate performance and signal to noise ratio.

2.8.1 Phase Shift Keying (PSK)

Phase shift keying (PSK), is widely used within a whole raft of radio communication system. It is particularly well suited to the growth area of data communication. Phase shift keying in digital modulation process conveys data by changing (modulating) the phase of a constant frequency. Reference signal (the carrier wave). the modulation is accomplished by varying the sine and the cosine inputs at a precise time. Any digital modulation scheme uses a finite number of distinct signals to represent digital data. PSK uses a finite number of phases each assigned a unique pattern of binary digit. Usually, each phase encodes an equal number of bits. Each pattern of bit forms the symbol that is represented by the particular phase. Demodulator which is designed specifically for the symbol-set used by the modulator, determine the phase of the received signal and maps it back to the symbol it represents.

2.8.1.1 Binary Phase Shift Keying (BPSK)

BPSK is the simplest form of phase shift keying (PSK) which convey data by changing, or modulating, two different phases of a reference signal. The modulation of BPSK is done using a balance modulator which multiplies the two signals applied at the input. For zero binary input the phase is $\mathbf{0^0}$ and for high input, the phase reversal is of $\mathbf{180^0}$.Therefore, it handles the highest noise level or distortion before the demodulator reaches an incorrect decision. That makes it the most robust of all the PSK. It is, however, only able to modulate at 1 bit/symbol and so is unsuitable for high data-rate applications.

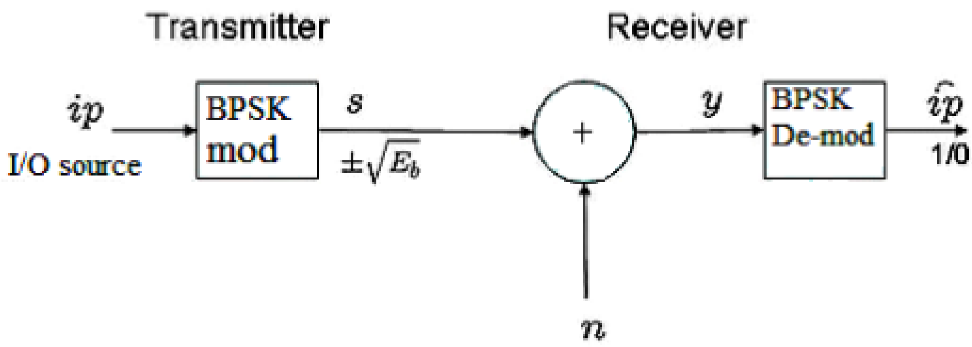

Figure 2.4: Block Diagram of BPSK transmitter- receiver (mustafa sami ahmed, 2020)

2.8.2 M-ary Quadrature Amplitude Modulation (M-QAM)

QAM is a hybrid modulation technique that takes its implementation by combining variations of both the amplitude A (t) and phase Ø (t) of the signal. The QAM signal transmits signals by modulating the amplitude of two sinusoidal carrier waves which are orthogonal to each other (which is what "quadrature" means: 90 degrees out of phase). QAM is widely used in modems designed for telephone communications, and is used in satellite systems, wireless networks, and mobile cell phone systems. The structure is similar to that of PSK, but the amplitude takes on a different range of value pairs. QAM has different versions identified by various orders, of which some of the most commonly used versions of QAM includes 8-QAM, 16-QAM, 32-QAM, 64-QAM, 128-QAM, 256-QAM and 1024-QAM.

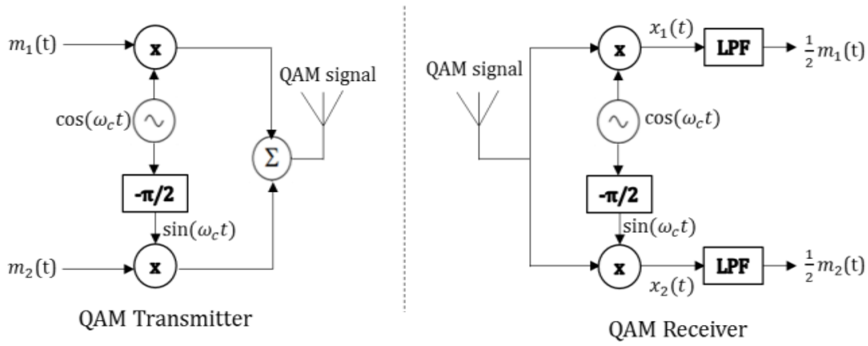

Figure 2.5: QAM Modulation and Demodulation Blocks (Webb, 1992)

2.8.3 Mathematical Analysis for M_PSK and M_QAM

In digital communication system design, the main objective is to receive data as similar as the data sent from the transmitter. It is important to analyze the system in terms of probability of error to view the system's performance. Each modulation technique has different performance while dealing with signals, which normally are affected with noise. General explanation for probability of error is explained in this section. General equation for the output signal that is affected with the additive white Gaussian noise can be shown in Equation below. If $x(t)$ is the true signal, then $y(t)$ is the signal corrupted by noise, $n(t)$.

$$y(t) = x(t) + n(t) \qquad (2.2)$$

The general form for BPSK follows the equation:

$$s_b(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \pi(1-n)),\, n = 0,1 \qquad (2.3)$$

This yields two phases, 0 and π. In the specific form, binary data is often conveyed with the following signals:

$$s_0(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \pi) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \quad for\ binary\ 0, \qquad (2.4)$$

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \quad for\ binary\ 1 \qquad (2.5)$$

Where;

f_c is the frequency of the carrier wave

T_b, bit duration

E_b, energy per bit

Hence, the signal-space can be represented by the single basis function

$$\emptyset(t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_c t) \qquad (2.6)$$

The general formula for probability of error or bit error rate of M- PSK for AWGN channel is given as:

$$P_b = \frac{1}{m} erfc\sqrt{\frac{mE_b}{N_o}}\sin\left(\frac{\pi}{M}\right) \qquad (2.7)$$

Where M= 2^m, m=2,3,4,5,

BER calculation for M- array QAM

QAM is a modulation technique where the amplitude is allowed to vary with phase. QAM signaling is viewed as a combination of ASK and PSK. Also, it can be viewed as an ASK in two dimensions. It is such classes of non-constant envelope schemes that can achieve higher bandwidth efficiency than M array PSK with the same average signal power. The BER is an important factor in determining and evaluating the performance of modulation schemes.

The general bit error rate formula for M-array QAM is:

$$P_b = \frac{2}{k}\left(1 - \frac{1}{\sqrt{M}}\right) erfc \sqrt{\frac{3E_b k}{2N_o(M-1)}} \tag{2.8}$$

where k $= \log M$,

$erfc$ is the complementary error function defined as $erfc = 1 - erf$

$\frac{E_b}{N_o}$, signal to noise ratio

For 16-QAM M=16; k=4

$$P_b \approx 0.375 erfc \sqrt{\frac{2E_b}{5N_o}} \tag{2.9}$$

For 32-QAM M=32; k=5

$$P_b \approx 0.33 erfc \sqrt{\frac{15E_b}{62N_o}} \tag{2.10}$$

For 64-QAM M=64; k=6

$$P_b \approx 0.292 erfc \sqrt{\frac{E_b}{7N_o}} \tag{2.11}$$

For 256-QAM M=256; k=8

$$P_b \approx 0.234 erfc \sqrt{\frac{12E_b}{255N_o}} \tag{2.12}$$

For 1024-QAM M=1024; k=10

$$P_b \approx 0.19375 erfc \sqrt{\frac{15E_b}{1023N_o}} \tag{2.13}$$

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Simulation Tool

MATLAB is widely used in all areas of applied mathematics, in education and research at universities and in the industry. MATLAB stands for Matrix Laboratory and the software is built up around vectors and matrices. This makes the software particularly useful for linear algebra but MATLAB is also a great tool for solving algebraic and differential equations and for numerical integration. MATLAB has powerful graphic tools and can produce nice pictures in both 2D and 3D. It is also a programming language, and is one of the easiest programming languages for writing mathematical programs. MATLAB also has some tool boxes useful for signal processing, image processing, optimization, etc.

3.2 Multicarrier Modulation for 5G Systems

Wireless communication techniques can be divided in to two categories (i.e., single carrier modulations and multicarrier modulations). Single carrier modulation systems exploit only one signal frequency to transmit data symbols. Differently, Multi-carrier modulation is a method of transmitting data by dividing it into multiple components and sending each of these components over separate carrier signals. It is used for data transmission as it is able to provide effective signal waveform which is spectrally efficient and resilience to narrow band fading and multipath effects. Originally the concept of Multicarrier modulation required the use of several channels that were separated from each other by the use of steep sided filters of they were close spaced. In this way interference from the different channels could be eliminated. Therefore, the symbol interval in multicarrier nodulations is longer than that of single carrier modulations, which gives MCM systems stronger ability against the ISI than single carrier modulations. There are many forms of multicarrier modulation techniques that are in use of being investigated for use. Some of the most widely known schemes are OFDM, FBMC and UFMC.

3.3 Orthogonal Frequency Division Multiplexing (OFDM)

Another sort of multichannel system is the OFDM transmission technique. Chang of Bell Labs introduced OFDM in 1966. Weinstein and Ebert refined it in 1971 by including a guard interval to increase orthogonality in transmission channels affected by multipath propagation. OFDM is a type of multicarrier modulation that divides a stream into numerous parallel bit streams and modulates each of these data streams onto individual subcarriers to transmit data. Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), digital video broadcasting terrestrial (DVB-T), and the downlink of the current 4G cellular standard LTE all use OFDM on the physical layer. In OFDM the entire bandwidth is filtered to achieve high data rates and to reduce ISI.

3.3.1 Basic principles of OFDM

The block diagram shown below describes, the input data coded with convolution code the constellation points are map after a group of channel bits are grouped together. The data is serial represented by complex number so mapping technique is used. The streams are then time sequenced using a serial to parallel (S/P) converter and an Inverse Fast Fourier Transform (IFFT) block. The modified data is organized according to the needs of transmission subcarriers. In every block of data cyclic prefix is inserted, the OFDM symbol time sequences are extended (Almutairi et al., 2019). The CP is a copy of the symbol's later portion that is added at the beginning of the sequence, and it should be larger than the network deferral spread to reduce inter symbol interference (ISI) caused by the influx of various OFDM symbols with different delays. The resulting digital signal is converted to analog and broadcast on the channel. After removing the CP, the signal is rebuilt into digital form at the receiver end, and the Fast Fourier Transform (FFT) is obtained in the received streams. Finally, the parallel streams are combined into a single stream that is identical to the one that was originally broadcast.

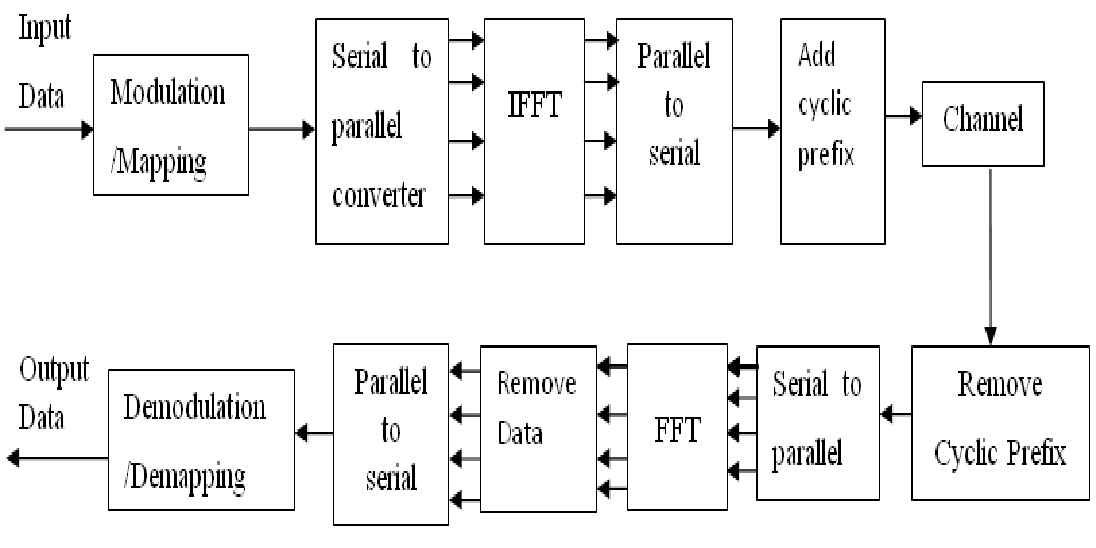

Figure 3.1: Block Diagram of OFDM Transceiver

Some of the advantages and disadvantages of OFDM are enumerated below:

Advantages

- OFDM spectrum is composed of overlapped narrow subcarriers. This makes efficient usage of frequency spectrum compared to FDM method.
- It is less sensitive to sampling time offset impairments compare to SC system
- It is robust against narrow band co-channel interference.

Disadvantages

- Has high out-of-band emissions because of the use of rectangular window in time domain
- Interference between the unsynchronized signal in the adjacent bands
- Reduced spectral efficiency due to the CP employed
- Has high PAPR and high bit error rate

3.4 Filter Bank Multicarrier (FBMC)

FBMC is a type of multi-carrier modulation in which the carriers are filtered to produce a waveform that is more spectrally efficient. Chang and Saltzberg were the first to introduce the FBMC system. Chang proposed employing Vestigial Side-band modulation to convey the asset of parallel (real valued) pulse amplitude modulated (PAM) symbols (VSB). FBMC is a development of OFDM and aims to overcome some of the issues that were encountered with OFDM.

3.4.1 Basic Principles of FBMC

The input signal is first converted from serial to parallel form and then passed through synthesis filter bank and then it is converted back to serial form after coming out of synthesis bank. After this it can be seen in that in the receiver side after the signal passes through the channel it is converted to parallel form by serial to parallel converter and passed through analysis filter bank. Finally, when the output signal is obtained, it is again converted to serial form by parallel to serial converter. A filter bank is a system in FBMC that has a group that processes a common input into a shared output. The analysis filter bank (AFB) and the synthesis filter bank (SFB) are the two main types of filter banks. Based on the filter qualities, AFB is used to analyze the input signal. Before mixing different signals to form a new composite signal, SFB is employed to filter them. SFB and AFB are implemented using an IFFT followed by a polyphase network structure or an FFT followed by a polyphase network structure, respectively.

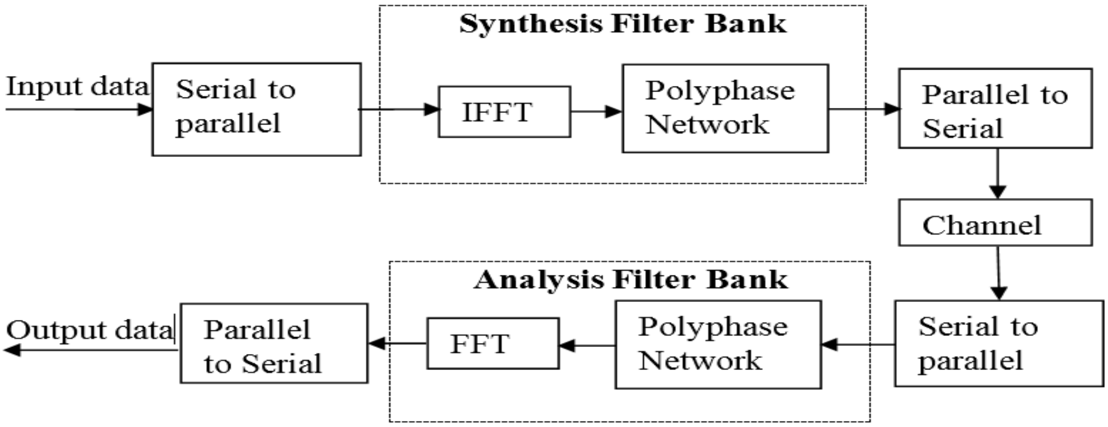

Figure 3.2: Block Diagram of FBMC

Some of the advantages and disadvantages of FBMC are enumerated below:

Advantages

- FBMC is able to provide a spectrum efficient and more selective system.
- The cyclic prefix, CP required for OFDM is not needed thereby freeing up more space for real data.
- Provide robust narrowband jammers.

Disadvantages

- The use of MIMO with FBMC is very complicated and as a result few systems have investigated the use of these two techniques together.
- The design of wide bandwidth and high dynamic range systems with FBMC provides some significant RF development challenges.
- FBMC is more complicated than OFDM - it introduces an overhead in overlapping symbols in the filter bank in the time domain.

3.5 Universal Filtered Multi-Carrier (UFMC)

UFMC collects the advantages of OFDM and FBMC. UFMC uses sub band filtering; these sub bands consist of number of sub-carriers. OOBE in UFMC is much lesser than OFDM because of the filters used. Sub band filtering reduces the filter lengths in UFMC which makes it suitable for short data transmission. Because of the QAM modulation employed at the transmitter, UFMC is compatible with MIMO methods. For both perfect and non-perfect synchronization between user equipment (UEs) and base stations, UFMC surpasses OFDM (BSs). The UFMC time-frequency resource efficiency in short bursts has been compared against OFDM and FBMC. Furthermore, the short filter lengths bring a significant spectral efficiency advantage over FBMC in case the transmission lasts only a few multicarrier symbols, when accounting for the time overhead of the filter.

3.5.1 Basic principles of UFMC

The operation of UFMC is based on filtering a group of sub-bands, instead of filtering a single carrier or the entire band. In the UFMC system, the input has the form of a set of complex QAM symbols. These symbols are then serial-to-parallel converted and divided in to B sub-bands, containing the K symbol each. Frequency domain symbol S= [$S_{1K}S_{2K}\ldots S_{BK}$] are then converted to time domain symbols X= [$X_{1K}X_{2K}\ldots. X_{BK}$] by the IFFT block. Since the number of complex symbols in each sub-band is lower than that of IFFT points N, the rest of the block is padded with zeros. The output of IFFT is converted from parallel to serial. Each padded zero symbol is filtered with length L, with a specific side lobe attenuation level and then added and to transmit to the wireless channel (Ambatali & Marciano, 2017).

UFMC has more elasticity for filtering every subband by its spectrum.it may allow the scheme to adapt service types by regulating subband and filter coefficients only. UFMC may provide simultaneous access for two different applications, in two disimilar sub-bands, without creating inter symbol band interference (ISBI) due to the reduction of OOB.

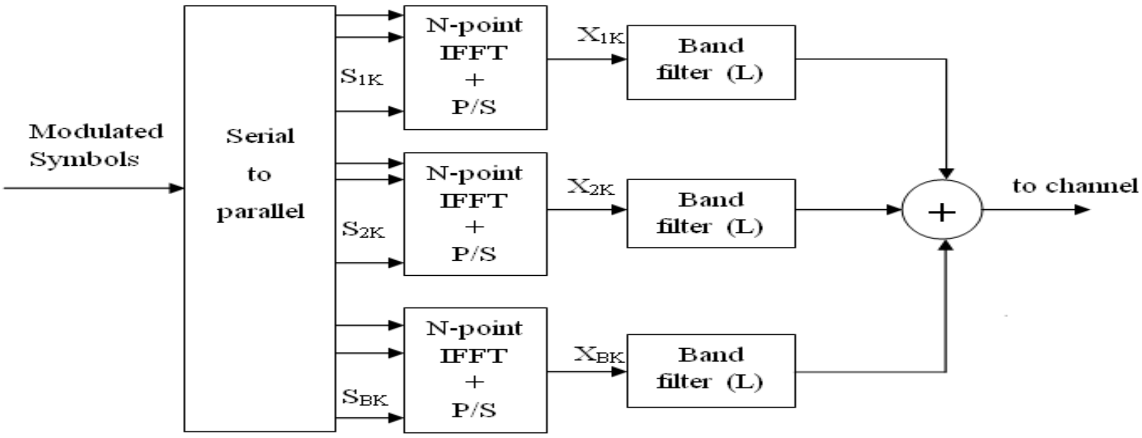

Figure 3.3: Universal Filtered Multicarrier Transmitter

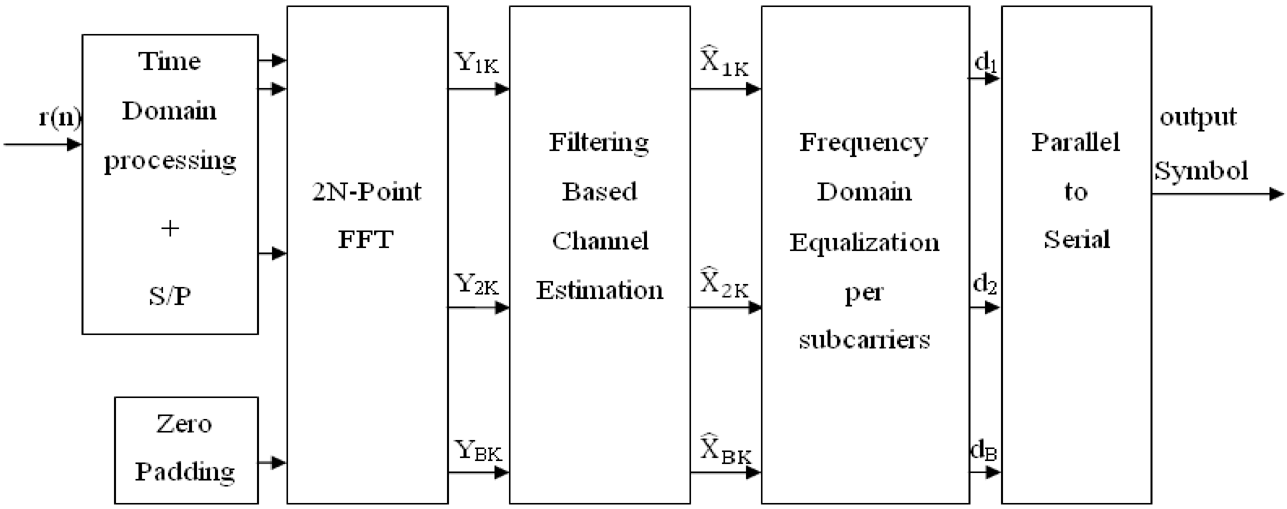

Figure 3.4: Universal Filtered Multicarrier Receiver

Sub-band filtering now extends the receive time window to the next of two power lengths for the FFT process, where each alternate value corresponds to a subcarrier main lob on the receiver side. Due to side lobes in the spectrum, there are interference issues that can be resolved with the use of equalizers. Every alternate frequency value corresponds to the main lobe of the subcarrier, and it is capable of equalizing the combined effect of the channel and sub band filtering. Because no channel effects are modeled in this paper, the sub-band filter was equalized, and noise was added to investigate the influence of noise on the transmitted signal.

3.6 Performance Metrics

3.6.1 Bit Error Rate (BER)

The bit error rate (BER) is the proportion of bits in a transmission that are incorrect when compared to the total number of bits received. It is commonly stated as ten to a negative power. It is an indication of how often a packet or other data units has to be retransmitted because of an error. Too high a BER may indicate that a slower date rate would actually improve overall transmission time for a given amount of transmitted data since the BER might be reduced, lowering the number of packets that had to be resent. In digital transmission, the number of bit errors is the number of received bits of a data stream over communication channels that have been altered due to noise, interference, distortion, bit synchronization errors, attenuation, wireless multipath fading, etc. BER can be used as one of the metrics to evaluate the performance of the system. The knowledge of the BER at any time can help analyze the channels, improve quality of service and enhance channel assignment in cognitive radio networks. For lower BER higher order modulation formats are preferable.

3.6.2 Power Spectral Density (PSD)

A composite signal is composed of several frequency components. Each frequency component corresponds to a signal. Such signals of different frequencies present in the signal respond differently to the channel noise conditions. The power spectral density of a signal is measured in dB/Hz and is a measure of the signal's power content vs frequency. It displays which frequencies have strong fluctuations and which frequencies have weak variations. Within a certain frequency range, energy can be obtained by integrating PSD within that frequency range. PSD depend on modulation level and also affected by windowing/filtering duration, the shape of filter and extra overheads.

3.6.3 Spectral Efficiency

Spectral efficiency (Bandwidth efficiency) describes the amount of data transmitted over a given spectrum or bandwidth with minimum transmission errors. A cellular network's spectral efficiency is equivalent to the maximum number of bits of data that can be transmitted to a specified number of users per second while maintaining an acceptable quality of service. Spectral efficiency is important to 5G, as data generation and processing demands increase with the deployment of 5G networks. It depends on FFT size and number of channels.

$$\eta_{OFDM} = m \times \frac{N_{FFT}}{(N_{FFT} + N_{CP})} \tag{3.1}$$

$$\eta_{FBMC} = \frac{m \times s \times N_{FFT}}{\frac{(2s-1)N_{FFT}}{2} + N_{FFT}k} = \frac{ms}{s + k - 1/2} \tag{3.2}$$

$$\eta_{UFMC} = m \times \frac{N_{FFT}}{(N_{FFT} + L - 1)} \tag{3.3}$$

Where;

m= modulation order

s= number of symbols

L= N_{CP}+1, in order to have the same spectral efficiency between UFMC and OFDM

N_{FFT} = FFT size

3.6.4 Peak-to-Average Power Ratio (PAPR)

The Peak to Average Power Ratio is the ratio of a sample's maximum powers in a transmitted symbol divided by the symbol's average power. When the sub-carriers in a multicarrier system are out of phase with each other, PAPR occurs. In multicarrier system there are a large number of independently modulated sub-carriers, which are out of phase with respect to each other. If more than one subcarrier achieves the maximum value at the same time, the output envelope will increase causing a peak in the output, and when these peaks are added up for transmission, a large peak value is reached that is very large compared to the average value of the sample. PAPR is defined by the following equation:

$$\text{PAPR} = \frac{\text{Peak Power}}{\text{Average Power}} \tag{3.4}$$

Table 3.1: Generalized Comparison of OFDM, FBMC and UFMC Techniques

Parameters	OFDM	FBMC	UFMC
Filter granularity	Whole band	Subcarrier	Sub band
Short bursts	No	No	Yes
flexibility	High	Medium	Medium
MIMO support	Yes	No	Yes
Out of Band Emission	Bad	Better	Good
Spectral Efficiency	High	High	Very high
Bit Error Rate	Moderate	Very high	High
PAPR	High	Very high	Low

3.7 System Model

The whole band of 'N' sub carriers is divided into numerous sub bands with a set number of sub carriers in each sub band. There is no requirement to use all sub bands for transmission in the transmitter part. Inverse Fast Fourier Transform (IFFT) is used to remove sub band carrier interference. Sub bands are computed and zeros are allocated for unallocated carriers at each N-IFFT. The frequency domain is converted to the time domain via IFFT (L. Wu et al., 2019).

The time domain signals from the IFFT are now sent through a Band filter with a length of 'L' block. Each sub band output is filtered using a band filter of the length 'L'. The IFFT outputs are filtered using parameterized side lobes attenuation. All of the band filters' outputs are now summed at the end and passed through the MIMO channel. The data bits are sent from the channel to the UFMC receiver. The 2N-point Fast Fourier Transform (FFT) is performed by the UFMC receiver. FFT translates time-domain data to frequency-domain data. Guard intervals of zeros are provided between subsequent IFFT symbols to prevent Inter Symbol Interference (ISI). ISI is caused by a delay in the transmitter filter. Even sub carriers are deleted in order to get the N-length frequency domain signal 'Y'. The data is now subjected to equalization, and the original data bits are recovered via symbol de-mapping (Dayana R & KumarR, 2018).

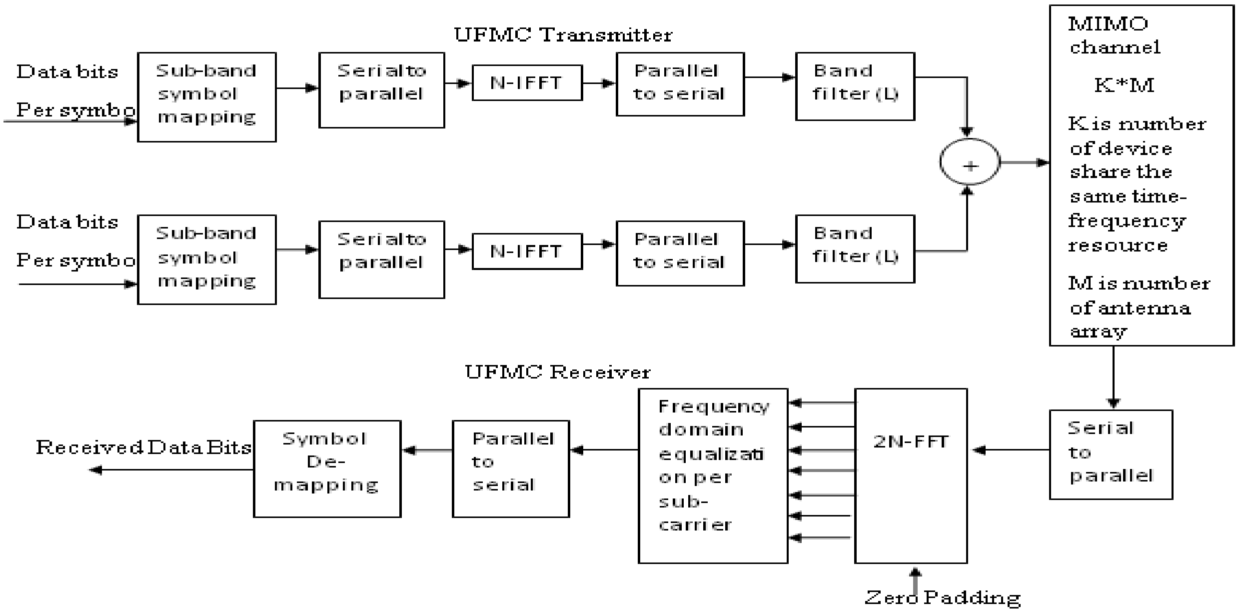

Figure 3.5: UFMC-MIMO Transceiver

3.8 Uplink Massive MIMO Transmission

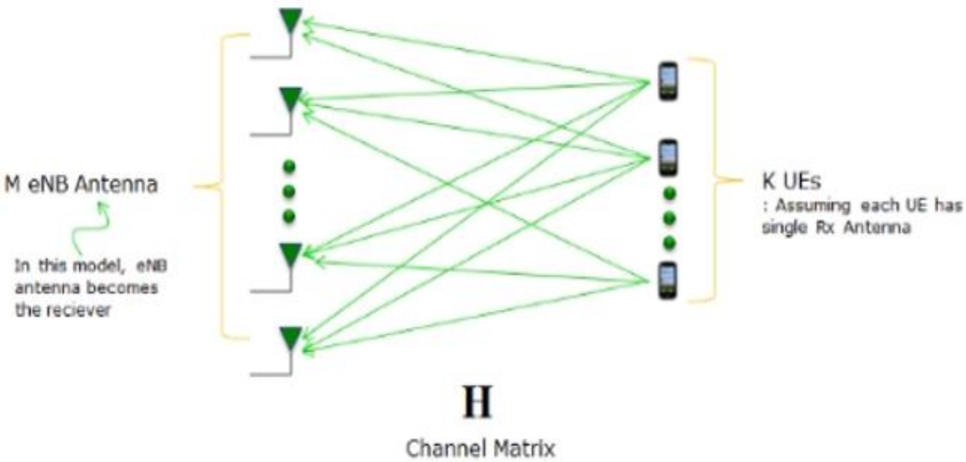

Figure 3.6: Uplink Massive MIMO system (Farhang-Boroujeny, 2011)

It is assumed that a BTS has large number of antenna and communicating with multiple UEs and each UE has only one antenna. We assume that the number of BTS antenna is very large comparing the number of UEs antenna. The channel matrix represented as;

$$H = \begin{bmatrix} h_{11} & \cdots & h_{1M_{Tx}} \\ \vdots & \ddots & \vdots \\ h_{M_{Rx}1} & \cdots & h_{M_{Rx}M_{Tx}} \end{bmatrix} \quad (3.5)$$

h_{mn}; m *is transmitter and* n *is receiver*

From the matrix expression the rows correspond to the number of receiver antenna and the columns correspond to the number of the transmitter antenna.

$$G = \underbrace{\begin{bmatrix} 0 & \cdots & 0 \\ 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{bmatrix}}\Big\} \text{M, small scale fading changes within wavelength or loss,}$$

K, Small scale fading between all antenna & UE

$$D = \underbrace{\begin{bmatrix} \beta_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \beta_k \end{bmatrix}}\Big\} \text{K large scale fading (path loss \& shadow fading),}$$

K

K^{th} diagonal element (large scale coefficient for UE-k),

From the above expressions the matrix H can be expressed as;

$$H = GD_{\beta}^{1/2} \tag{3.6}$$

Reverse link (Uplink)

The communication model for reverse path (from UE to BTS) is represented as;

$$X_r = \sqrt{\rho_r} H q_r + W_r \tag{3.7}$$

Where, X_r is received signal (M×1 vector)

ρ_r, Signal to Noise Ratio (SNR)

H, channel matrix (M×K)

q_r, transmitted signal QAM (K×1 vector)

W_r, Noise (Complex Gaussian Noise), CN (0, 1)

BTS can process the received data by Multiplying equation (3.7) with Hermitian transpose H^H with every term.

$$H^H X_r = \sqrt{\rho_r} H H^H q_r + H^H W_r \tag{3.8}$$

When number of BS antenna, M is much larger than the number of UE, K. we can assume each column of 'H' is orthogonal to each other.

$$H^H X_r \approx [M]\sqrt{\rho_r}[D_\beta] q_r + [H^H] W_r \tag{3.9}$$

Capacity for this channel can be described as;

$$C_{sum\_r} = \log_2 |[I_k] + \rho_r [H H^H]| \tag{3.10}$$

I_k is k×k identity matrix

When M is much larger than K, we can assume each column of H, is orthogonal to each other

$$C_{sum_{r(M\gg K)}} \approx \log_2\left|[I_k]+[M]\rho_r[D_\beta]\right| = \sum_{k=1}^{K}\log_2\left(1+[M]\rho_r[D_\beta]\right) \quad (3.11)$$

3.9 Channel Models

Channel refers to the path between transmitter and receiver whether it may be wired or wireless. Channel model is the mathematical modeling or mathematical equation describing the channel behavior between the transmitter and receiver. There are two types of channels depending on the motion between the transmitter and receiver; time varying channel and time invariant channel. If the transmitter and receiver or anyone is moving the channel is time variant. If the transmitter and receiver not moving and fixed at one location the channel referred to as time invariant. The examples are simple cable between transmitter and receiver or fixed WiMAX system where both station and subscriber premises equipment is fixed at one location and are not moving. There are different channel models used by communication design engineer for the purpose validating transmitter and receiver under design (Lv & Li, 2016).

Channel models for wireless systems have been primarily concerned with modeling the effects of the following parameters on the transmitted signal: path loss, delay spread, shadowing, Doppler frequency and/or speed. Parameters of specific interest to the MIMO channel are the joint antenna correlations and channel matrix singular-value distribution. Also of interest in the MIMO channel is the spatial diversity, which can be measured by analyzing the H-matrix singular-value distribution. In this way, the MIMO channel can be decomposed into a number of parallel SISO channels whose channel gains are directly related to the singular values of the H-matrix. By analyzing the distribution of the singular values in different environments, we can assess the performance gain of MIMO over other signaling techniques (Zheng et al., 2014).

3.9.1 Additive White Noise Gaussian (AWGN)

AWGN is a basic model use in information theory to mimic the effect of many random processes that occur in nature. The term additive means the noise is superimposed to the signal where it will limit the receiver ability to make correct symbol decisions. The term white refers to the idea that it has uniform power across the frequency band for the information system. It is analogy to the color white which has uniform emissions at all frequencies in the visible spectrum. The term gaussian describes the normal distribution in the time domain with an average time domain value of zero. As a result, AWGN is a channel model in which the sole communication impairment is a linear addition of wideband or white noise with a constant spectral density and gaussian amplitude distribution. Mathematically, thermal noise is described by a zero-mean Gaussian random process where the random signal is a sum of Gaussian noise random variable and a dc signal that is z = a +n, where pdf for Gaussian noise can be represented as follows where σ^2 is the variance of n.

$$p(z) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left\{\frac{z-a}{\sigma}\right\}^2\right] \tag{3.13}$$

A simple model for thermal noise assumes that its power spectral density $G_n(f)$ is a flat for all frequencies and is denoted as $G_n(f) = \frac{N_o}{2}$, where the factor of 2 to indicate that $G_n(f)$ is a two-sided power spectral density.

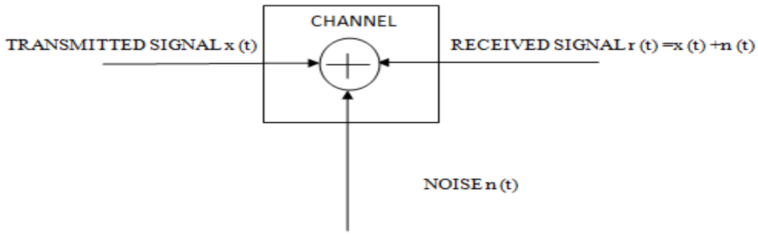

Figure 3.7: Block diagram of AWGN channel model

3.9.2 Rayleigh Fading

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal. It is applicable when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. Generally, there are two fading effects in mobile communications: large-scale and small-scale fading. Large-scale fading represents the average signal power attenuation or path loss due to shadowing effects when moving over large areas. whereas small-scale fading refers to the dramatic changes in signal amplitude and phase that can be experienced as a result of small changes in the spatial separation between a receiver and transmitter. Small-scale fading is also called Rice fading because the envelope of received signal can be represented by a Rice pdf.

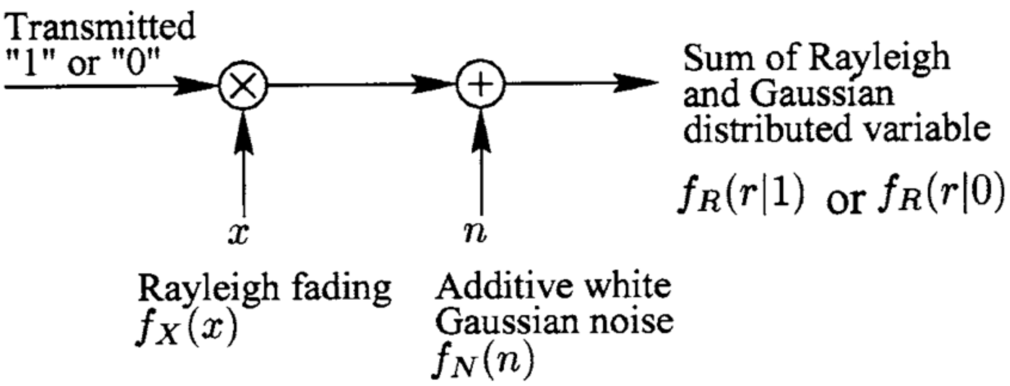

Figure 3.8: Block diagram of Rayleigh channel model (pal orten, 2002)

3.9.3 Rician Fading

Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself. The signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line-of-sight signal or some strong reflection signals, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.

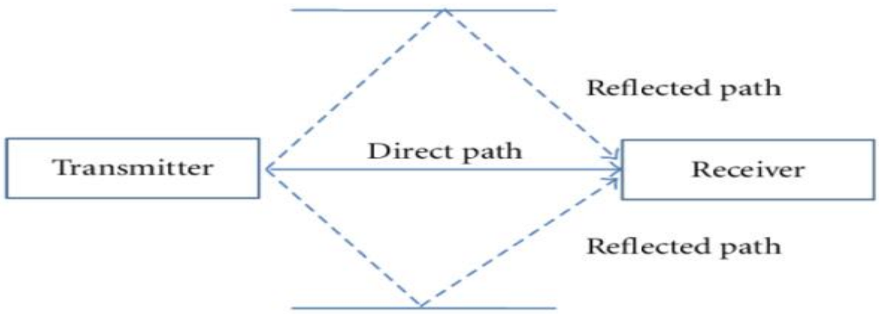

Figure 3.9: Block diagram of rician channel model

3.10 Prototype Filters

A prototype filter with better time-frequency performance is used, which has higher spectral efficiency and good out-of-band suppression in frequency domain. Adjustable windows have two or more independent parameters, namely, the window length, as in fixed windows, and one or more additional parameters that can control other window characteristics. The Kaiser window has two parameters and achieves close approximations to discrete prolate functions that have maximum energy concentration in the main lobe (Bendimerad et al., 2021). The Dolph-Chebyshev window has two parameters and produces the minimum main-lobe width for a specified maximum side-lobe level. The Kaiser and Dolph-Chebyshev windows can control the amplitude of the side lobes relative to that of the main lobe, and through the proper choice of these parameters, the amplitude of the side lobes relative to that of the main lobe can be controlled. In this paper we have seen different digital FIR filters to improve OOB emission and PSD efficiency of UFMC.

3.10.1 PHYDYAS Filter

This prototype filter was first developed and investigated by Bellanger. Then it was employed as a prototype filter in the physical layer for dynamic spectrum access and cognitive radio (PHYDYAS) European project. The PHYDYAS filter response contains $2K - 1$ coefficients in the frequency domain, where K is the overlap factor. This factor implies that the transition phase at the output of the receiver has a length of $K - 1$ symbols. For the PHYDYAS prototype filter, the overlapping factor, K and the frequency coefficients G_k are given. The continuous frequency response G (f) of the filter is obtained using the frequency coefficients through the interpolation formula for sampled signals and is given as

$$G(f) = \sum_{k=-(K-1)}^{K-1} G_k^2 \frac{\sin\left\{\pi\left(f - \frac{k}{NK}\right)NK\right\}}{NK\sin\left\{\pi\left(f - \frac{k}{NK}\right)\right\}} \quad (3.14)$$

3.10.2 Binomial Filter

Binomial Filter has also the demerit of wider bandwidth and higher level of adjacent-channel interferences in comparison to those of Dolph-Chebyshev filter. In our study, we have modified the coefficients of conventional Binomial Filter due to its limitations mentioned above. The Binomial coefficients, as designed by Panofsky and Brier in 1958 and Mitchell in 1966 is proportional to some weights (Ayvaz et al., 2019). We have used the following equation for the determination of the filter coefficients and hence named the filter as Fractional-Powered Binomial Filter (FPBF):

$$b_{FPBF} = [b_L]^{\beta} = \left[d_L \Big/ \sum_{L=0}^{Q} d_L \right]^{\beta} \quad (3.15)$$

The value of β can be controlled within the range $0 < \beta < 1$.

3.10.3 Kaiser Filter

James Kaiser of Bell Laboratories invented the Kaiser window, commonly known as the Kaiser–Bessel window. It's a one-parameter family of window functions used in spectrum analysis and finite impulse response filter design. The Kaiser window is a close approximation of the DPSS window, which maximizes energy concentration in the major lobe but is difficult to calculate. The most essential feature of the Kaiser Filter is the ability to use order of function to adjust the stop band and side lobe attenuation. The Kaiser-based UFMC filter has a smaller main lobe width than the Dolph-Chebyshev filter, indicating steepness, and hence delivers an ultimate power spectrum (Hammoodi et al., 2022). The coefficients of a Kaiser window are computed from the equation:

$$w(n) = \frac{I_O\left(\beta\sqrt{1-\left[\frac{n-N/2}{N/2}\right]^2}\right)}{I_O(\beta)} \text{ ,} 0 \leq n \leq N \quad (3.16)$$

Where;

I_O is the zeroth-order modified Bessel function of the 1st kind,

N is the length of the filter,

β = $\pi\alpha$,which is the order of the function.

Where; $\alpha = -20\log\log\delta$, stopband attenuation.

$$w(n) = \left\{\frac{1}{2} - \frac{\cos\cos\left[\frac{2\pi}{\alpha N}\right]}{2}\right\} \quad (3.17)$$

To obtain Kaiser Window that represents FIR filter with side lobe attenuation of αdB, use the following β.

$$\beta = \left\{\begin{matrix} 0.1102(\alpha-8.7), \alpha > 50 \\ 0.5842(\alpha-21)^{0.4} + 0.07886(\alpha-21), 50 \geq \alpha \geq 21 \\ 0, \alpha < 21 \end{matrix}\right\} \quad (3.18)$$

Larger β values give lower side lobe levels, but at the price of a wider main lobe.

3.10.4 Dolph-Chebyshev Filter

The function to be described is constructed using the well-known Chebyshev polynomials and was first used by Dolph (1946) to solve the problem of designing a radio antenna having optimal directional characteristics (Kraus 1988). It gives results similar to those achieved with the optimal filter but which is much simpler to implement (Lynch, 1997).

$$w_{cheby}(n) = (-1)^n \frac{\cos\left[N\cos^{-1}\left\{\beta\cos\left(\frac{\pi n}{N}\right)\right\}\right]}{\cosh[N\cosh^{-1}(\beta)]}, \quad n = 0,1,2, \dots \dots \dots N-1 \quad (3.19)$$

Where N is the Chebyshev window length,

The output is evaluated after filtering $S_k(l) = x_i(l) \otimes w(l)$

$\beta = \cosh\left[\frac{1}{N}\cosh^{-1}(10)^{\alpha}\right], \quad \alpha = 2,3,4\ \textit{which is the side lobe attenuation.}$

3.11 Channel Estimation Techniques in Massive MIMO Systems

This thesis also looks at the channel estimation method. A Massive MIMO system is based on a standard MIMO system in which the base station has a large number of antennas. Massive MIMO takes advantage of each base station's large number of antennas. It's worth noting that these benefits are conditional on the BS having accurate CSI estimates for each user. Denotes the deterministic pilot sequence of UE k in the supplied cell. Depending on the methodologies utilized, pilot-based channel estimation might employ a variety of algorithms. Three of the most popular channel estimation approaches are presented in this thesis. The methodologies of least squares (LS), mean minimum square error (MMSE), and element wise mean minimum square error (EW MMSE) covered (Özdogan et al., 2019).

3.11.1 The Minimum Mean Square Error Algorithm (MMSE)

The MMSE channel estimation approach is a computationally intensive estimate technique. MMSE channel estimation is a more accurate version of the LS channel estimation. The MMSE channel estimator is intended to reduce the estimation's mean square error (MSE). Note that the estimation error covariance matrix does not depend on the mean values. In other words, the estimation error has little interference from the LOS propagation and NLOS propagation. Moreover, the channel estimates of UEs are not independent, despite the assumption that the channels are independent. This is known as pilot contamination and happens since the UEs use the same pilot sequence.

3.11.2 Element-Wise MMSE Algorithm (EW-MMSE)

If the BS does not have knowledge of the entire covariance matrices, the EW-MMSE estimator can be implemented as an alternative. In this method, only the diagonals of the covariance matrices are needed and the correlation between the elements are ignored by the estimator. As a result, there are no matrix inversions and thus the computational complexity is greatly reduced as compared to the MMSE estimator.

3.11.3 Least Square Algorithm (LS)

The LS channel estimation method is a straightforward estimation methodology with a low level of complexity. If the BS has no prior information regarding mean and covariance, the non-Bayesian LS estimator can be utilized to get an estimate of the propagation channel. Since the mean values are not utilized as prior information, the interference terms are larger than when using the MMSE estimator. The LS estimates of the pilot-contaminating UEs are equal up to a scaling factor.

CHAPTER FOUR

4. RESULT AND DISCUSSION

The comparison of candidate multicarrier modulation methods is offered in this research. And also, the spectral efficiency evaluation of massive MIMO system using MMSE and LS channel estimation techniques discussed. Table 4.1 lists the general simulation parameters we have used and the MATLAB platform is used to assess performance. The settings used in this simulation can change depending on the comparison measurements.

Table 4.1: Parameters for the Waveforms Simulation

Parameters	Value
General parameters	
FFT size	512/1024
Subcarrier spacing	15KHz (same as LTE)
Bits per symbol	6,8,10
Channel Bandwidth	10MHz
SNR (dB)	-10~ 20(dB)
OFDM parameters	
Length of Cyclic prefix	72
FBMC parameters	
Overlapping factor	K=5
Prototype Filter	PHYDYAS filter
UFMC parameters	
Filter length	73
Side-lobe attenuation	60
Number of sub bands	24
Sub band size	12
Filtering techniques	Dolph-Chebyshev/FPBF/kaiser

Simulations and observations achieved under various channel parameters have been used to compare the performance of OFDM, FBMC, and UFMC schemes. QAM was chosen because it has a higher spectral efficiency than other modulations and is often used for data transmission.

4.1 Bit Error Rate (BER) Comparison

In this section the BER performance UFMC, OFDM & FBMC is investigated under AWGN channel model. In simulation BER of UFMC system analyzed for different types at higher order QAM (1024-QAM). For the system to have good performance the bit error rate should be reduced.

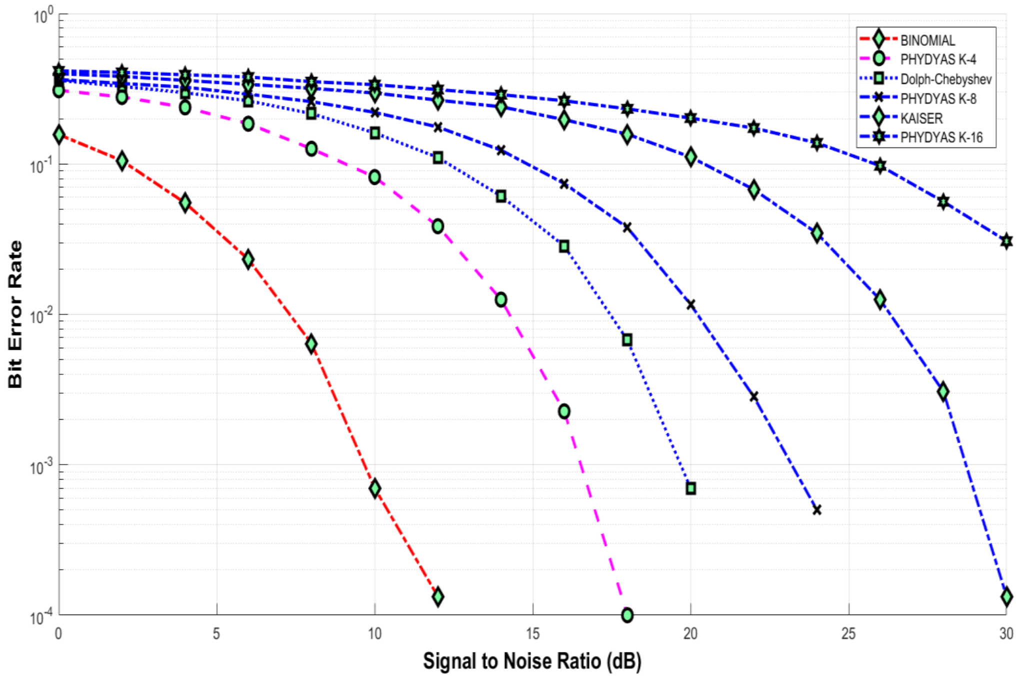

Figure 4.1: BER vs. SNR of UFMC for different Prototype Filters at 1024-QAM levels

Figure 4.1 Describe the BER performance of UFMC for different prototype filter in the case of high-order QAM level. At the lower value of SNR, around 12dB, binomial filter has lowest BER. This reduction indicates that the high sensitivity occurred at the receiver which makes the system to have better performance.

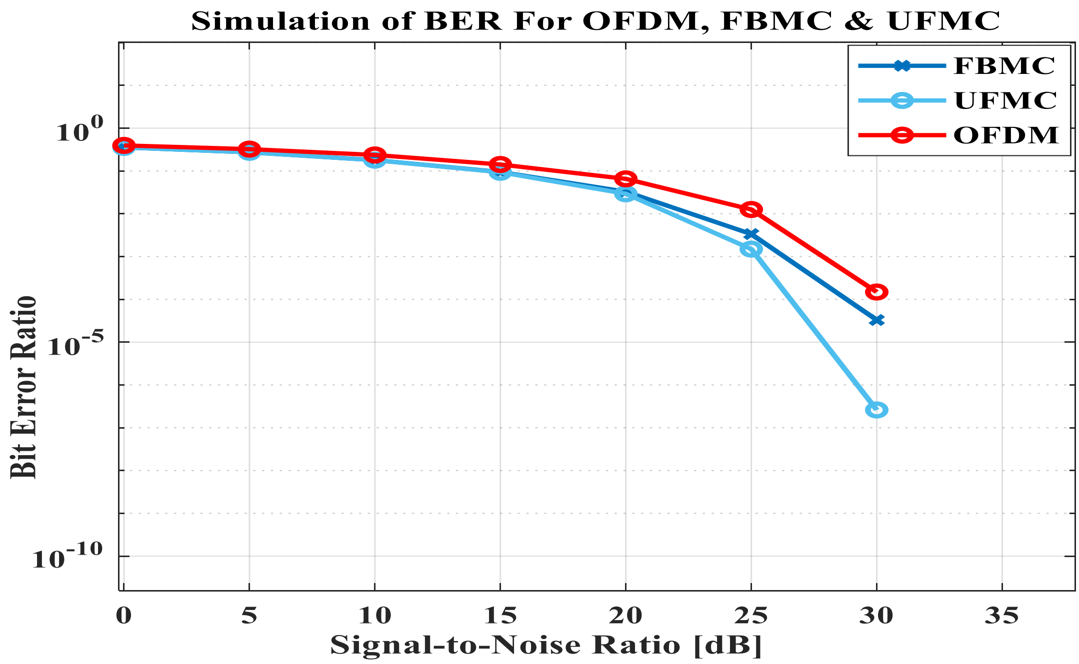

Figure 4.2: BER performance of OFDM, FBMC & UFMC using 1024QAM

From figure 4.2 the comparison of Bit Error Rate of all the three candidate waveforms concerning with SNR. The figure shows that as there is a rise in the SNR the BER of UFMC reduced compared to OFDM & FBMC multicarrier modulation techniques.

Table 4.2: BER Comparison of OFDM, FBMC and UFMC based on SNR values for 1024-QAM

SNR (dB)	BER for 1024QAM		
	OFDM	FBMC	UFMC
5	0.3239	0.273	0.2727
10	0.2366	0.1792	0.1787
15	0.1416	0.09461	0.09312
20	0.06547	0.03269	0.02916
25	0.01261	0.003381	0.001469
30	0.0001417	0.00003828	$1.302*10^{-7}$

4.2 Peak to Average Power Ratio (PAPR)

The preferred modulation techniques are 16QAM, 64QAM, 256QAM and 1024QAM. The length of filter length in UFMC is approximately equal to the length of cyclic prefix in OFDM. In order to send a greater number of subcarriers and access more users we have to increase FFT size. The program is simulated by varying modulation techniques with different prototype filter.

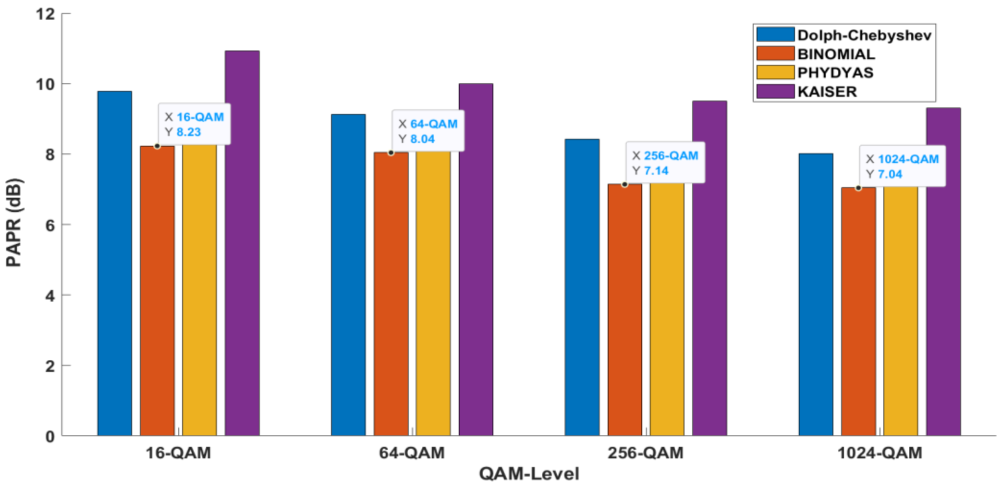

Figure 4.3: PAPR of UFMC for Four different Prototype Filters and Four different QAM

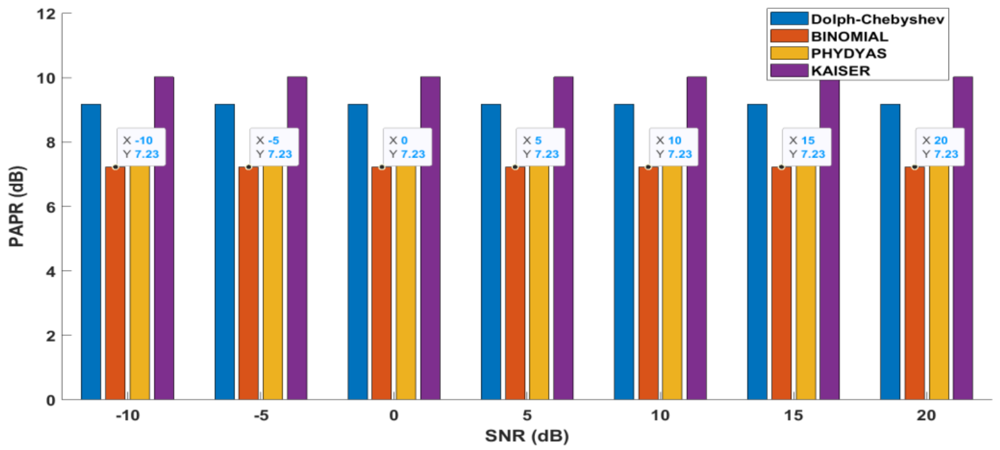

Figure 4.4: PAPR vs SNR of UFMC for different Prototype Filters and different QAM levels

Figure 4.4 results shown that the Reduction of PAPR of UFMC using Binomial Filter is better. In the case of 1024-QAM Prototype Binomial Filter is much better Reduction of PAPR than lower level QAM. The above figure indicates that PAPR does not vary with the variation of SNR value.

4.3 Power Spectral Density (PSD) Comparison

As a function of normalized frequency, the normalized power spectral density of OFDM and UFMC symbols with sub-carriers is shown below. Because the energy is concentrated in the main lobe of the graph below, it is intuitively evident that the modulations have different side-lobe radiations. The spectral density shows the signal's strength with time (i.e., the maximum bandwidth over which the bits can be successfully sent). The spectral density of a modulation is more efficient if the strength is closer to the normalized frequency. To support asynchronous transmission, having lesser OOB emission is advantageous. From figure the spectrum utilization is very good in UFMC system than OFDM system.

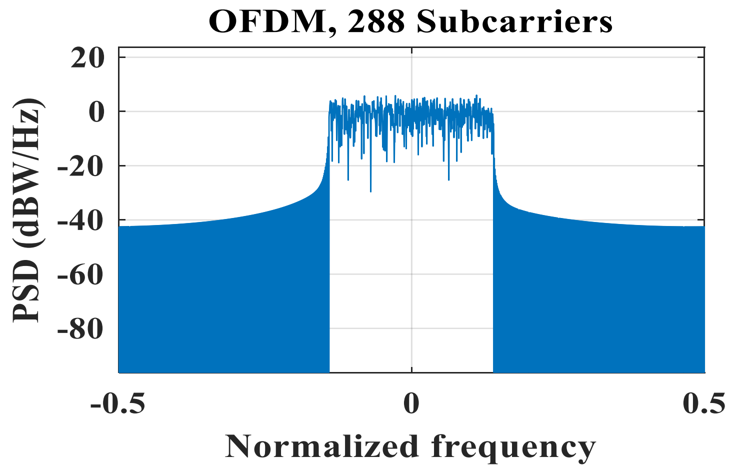

Figure 4.5: Power Spectral Density of OFDM

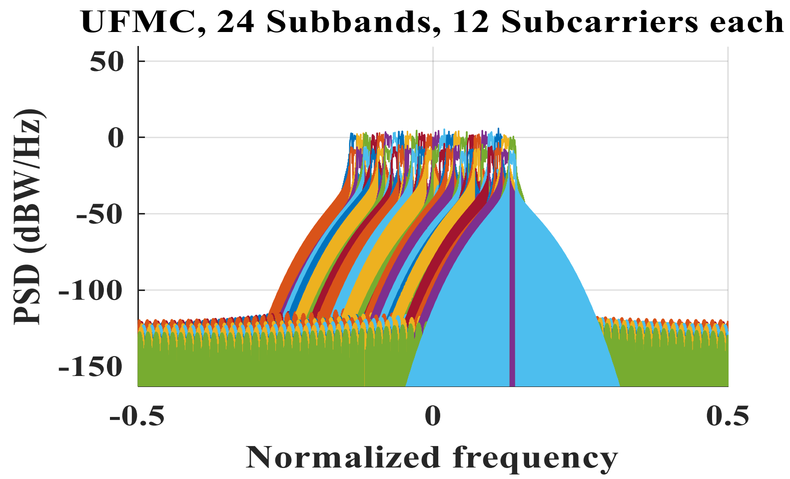

Figure 4.6: Power Spectral Density of UFMC

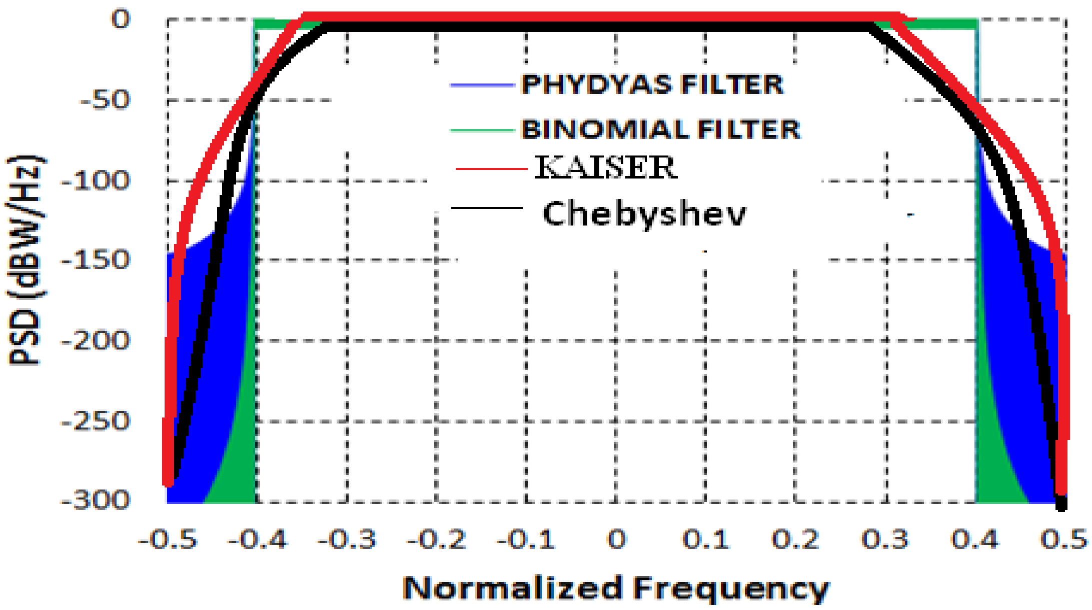

Figure 4.7: PSD of UFMC using different Prototype Filters

From figure (4.7) Power spectral densities (PSD) of UFMC with different Prototype Filters are shown, in the case Binomial Filter the reduction of out of band interference is better than other prototype filters.

4.4 Spectral Efficiency Comparison

In this section, the spectral efficiency of the candidate waveforms OFDM, FBMC and UFMC is evaluated. Spectral efficiency vs. burst duration, represented in bits per second per Hertz. We use LTE 10MHz with 1024QAM symbol mapping and an FFT size of 1024 to calculate the parameter. The spectral efficiency of CP-OFDM and UFMC is a function of FFT size, modulation order, and modulation parameters, not the burst duration.

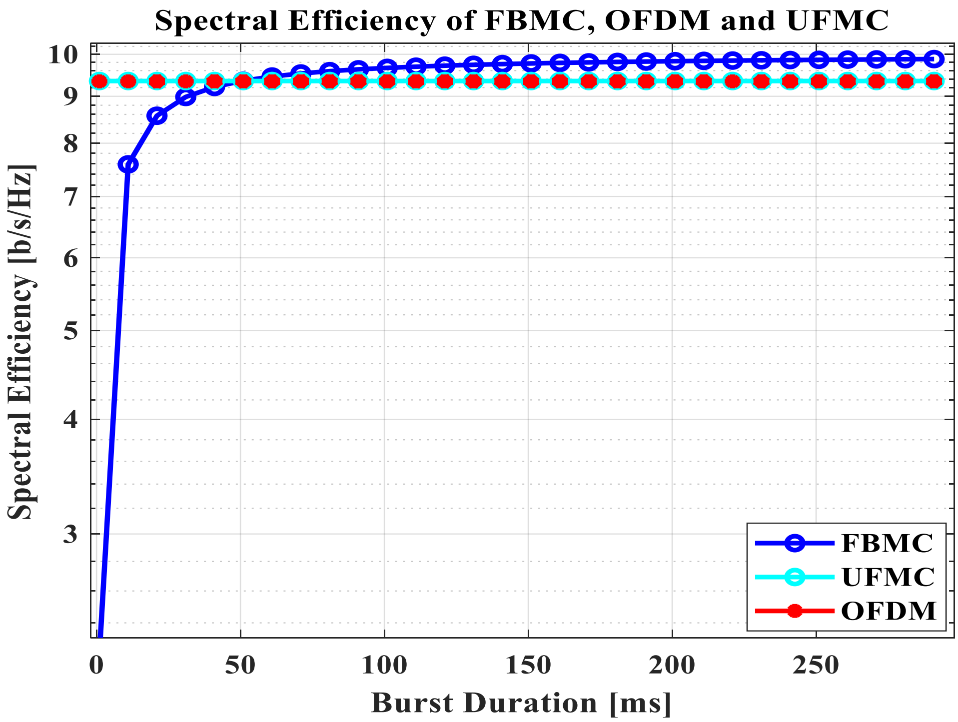

Figure 4.8: Spectral efficiency of OFDM, FBMC and UFMC at FFT size N=1024, filter length equal with that of cyclic prefix

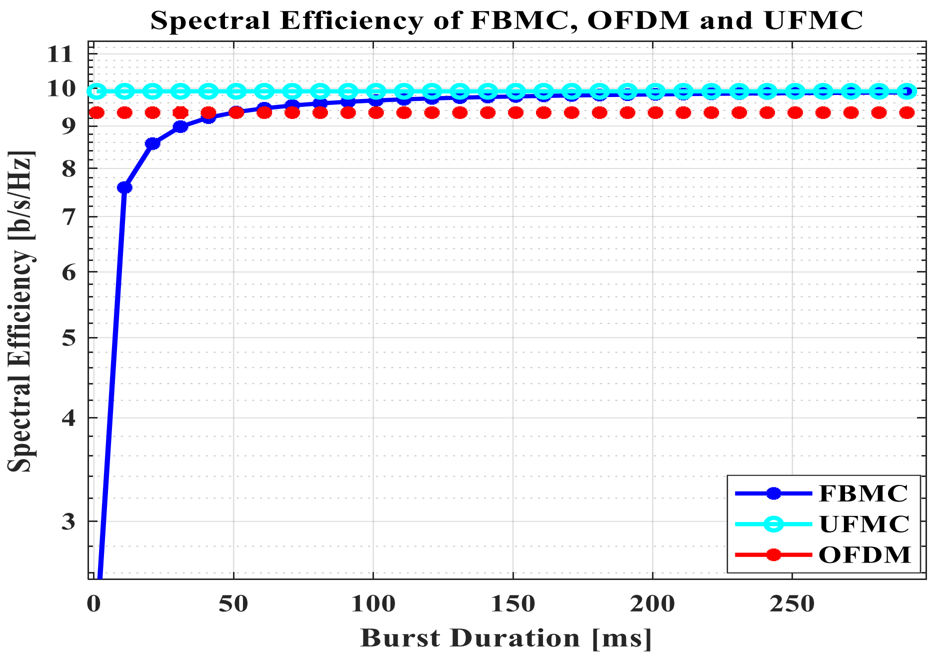

Figure 4.9: Spectral efficiency analysis of OFDM, FBMC and UFMC when FFT size N=1024, filter length less that the cyclic prefix

From the simulation graph we observed that the spectral efficiency of UFMC and OFDM overlapped if the filter length of UFMC is equal to the number of Cyclic Prefix added in to the OFDM. The spectral efficiency of FBMC depends on the burst duration. For the reason of this it is not suitable for short distant communication.

4.5 Performance Evaluation of Massive MIMO system using Rician and Rayleigh Fading channels

From the above discussion, we have seen that UFMC is best suited multicarrier modulation schemes because of its high spectral efficiency, energy efficiency, and reduced BER. Among the filters we have used, the binomial filter has great effect for the reduction of PAPR of UFMC, which gives high energy efficiency for the system and is also important for the massive MIMO system. In order to integrate the UFMC waveform with the MIMO system for evaluating the spectral efficiency binomial filters are well suited.

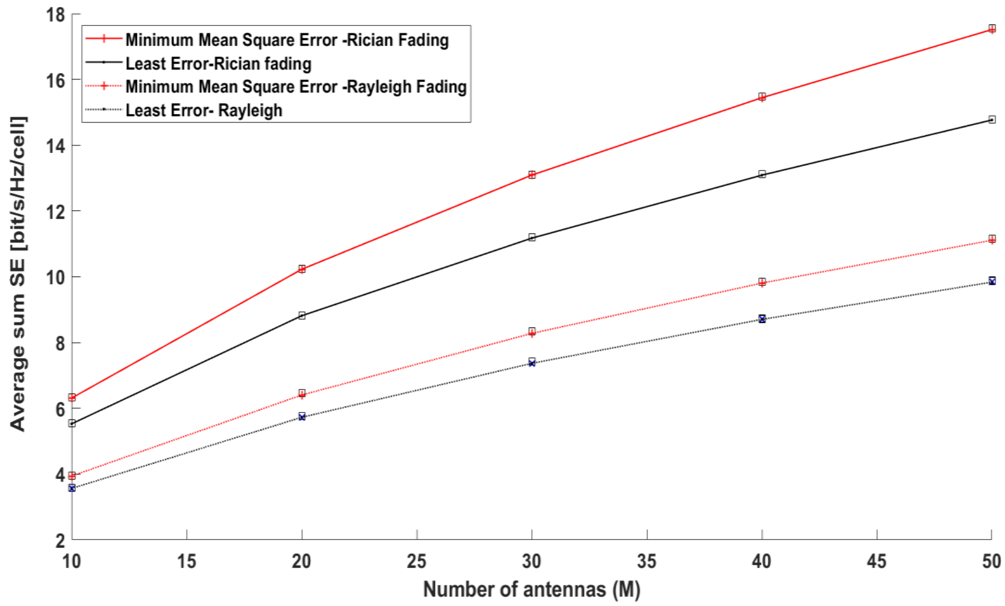

Figure 4.10: Uplink SE for Number of User = 10 as a function of the number of BS antennas for different channel estimators using binomial filter at 1024 –QAM

Figure 4.10 shows the sum Uplink (UL) spectral efficiency (SE) in averaged over different user equipment (UE) locations and shadow fading realizations. For Rician fading, the performance of minimum mean squared error (MMSE) and least error (LS) are very close and MMSE performs better than LS since it utilizes knowledge of the channels' mean values. In the case of Rayleigh fading, MMSE estimation is still the better choice.

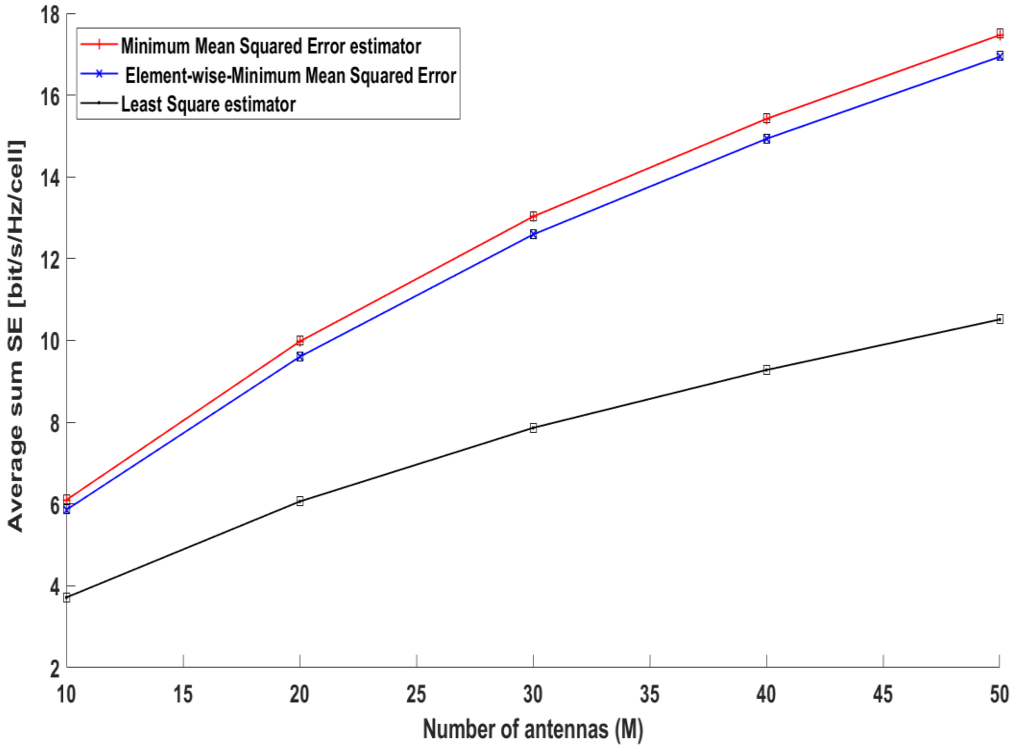

Figure 4.11: Average Uplink sum SE for Number of User =10 as a function of BS antennas for different channel estimators in which all users are line of sight with BS

In Figure 4.11 we considered a scenario with spatially correlated Rician fading channels between every pair of BSs and UEs which may not be possible in practice. Compared the case where only some UEs have LOS (Fig. 4.11), the average UL sum SEs are higher since the existence of a LOS component improves the SE.

5 CONCLUSSION AND RECOMMENDATION

5.1 CONCLUSSION

This thesis compares and contrasts the performance of UFMC modulation schemes with FBMC and CP-OFDM in terms of power spectral density, BER, and spectral efficiency. The transmitted data and the signal travelling over the channel were identical in each case. The research examines the different benefits and drawbacks of each modulation strategy. The tests performed for UFMC and the limitations of existing OFDM system conclude that the integration of the new candidate waveform UFMC is possible for the existing 4th generation system and for 5th generation systems. Since the objective of 5G system is to reduce the problems faced in the 4G (OFDM) system, and that is through using the banks of filter for each symbol instead of using the CPs at each symbol in each sub-carrier. Thus, by removing the cyclic prefix in OFDM and lengthy filter in FBMC we can increase the spectral efficiency of the systems. Also reduce the side lobes that cause high ISI, ICI, OOB, and PAPR. Backward compatibility with well-known OFDM techniques is also maintained with UFMC. In this paper we also discussed the spectral efficiency of uplink massive MIMO system versus with number of antennas for 10 number of users per cell using Rayleigh fading channel and rician channel by MMSE and LS channel estimation techniques. The Massive MIMO systems implementation can enhance the system performance significantly and the requirements of 5G can be achieved by combining the UFMC and MIMO together to get the desired modulation scheme and antenna configuration to make system more reliable and economical.

5.2 RECOMMENDATION

In this thesis, three modulation candidates OFDM, FBMC and UFMC were compared depend on PSD, BER, PAPR and spectral efficiency performance parameters. Also, we analyzed the spectral efficiency of uplink massive MIMO transmission using binomial filter under rician and Rayleigh channel when the numbers of users are 10. For future work PAPR of UFMC further decreased by using PAPR reduction techniques and optimization techniques.

Research Fund Acknowledgement

This research thesis was funded by Adama Science and Technology University under the grant number ASTU/SM-R/514/22, Adama, Ethiopia.

6 REFERENCES

Al-Rayif, M. I., Seleem, H. E., Ragheb, A. M., & Alshebeili, S. A. (2020). Papr reduction in ufmc for 5G cellular systems. *Electronics (Switzerland)*, *9*(9), 1–15. https://doi.org/10.3390/electronics9091404

Almutairi, A. F., Al-Gharabally, M., & Krishna, A. (2019). Performance Analysis of Hybrid Peak to Average Power Ratio Reduction Techniques in 5G UFMC Systems. *IEEE Access*, *7*, 80651–80660. https://doi.org/10.1109/ACCESS.2019.2916937

Alrashdi, A. M., Kammoun, A., Muqaibel, A. H., & Al-Naffouri, T. Y. (2020). *Optimum M-PAM Transmission for Massive MIMO Systems with Channel Uncertainty*.

Ambatali, C. D. M., & Marciano, J. J. S. (2017). Performance evaluation of the UFMC scheme under various transmission impairments. *2016 IEEE International Conference on Communication, Network, and Satellite, COMNETSAT 2016 - Proceedings*, 24–28. https://doi.org/10.1109/COMNETSAT.2016.7907410

Ayvaz, E. N., Maras, M., Gomec, M., & Ozen, A. (2019). A novel waveform design based on lifting wavelet transform for the 5G beyond. *2019 42nd International Conference on Telecommunications and Signal Processing, TSP 2019*, 660–663. https://doi.org/10.1109/TSP.2019.8769042

Banelli, P., Buzzi, S., Colavolpe, G., Modenini, A., Rusek, F., & Ugolini, A. (2014). Modulation formats and waveforms for 5G networks: Who will be the heir of OFDM?: An overview of alternative modulation schemes for improved spectral efficiency. *IEEE Signal Processing Magazine*, *31*(6), 80–93. https://doi.org/10.1109/MSP.2014.2337391

Bendimerad, M. Y., Senhadji, S., & Bendimerad, F. T. (2021). *Prototype Filters and Filtered Waveforms for Radio Air-Interfaces: A Review*.

Björnson, E., Hoydis, J., Labs, B., & Sanguinetti, L. (2020). Massive MIMO Networks: Spectral, Energy, and Hardware Efficiency. *Foundations and Trends in Signal Processing*, *11*(3–4), 154–655. https://doi.org/10.1561/2000000093.Simulation

Cai, Y., Qin, Z., Cui, F., Li, G. Y., & McCann, J. A. (2018). Modulation and Multiple Access for 5G Networks. In *IEEE Communications Surveys and Tutorials* (Vol. 20, Issue 1, pp. 629–646). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/COMST.2017.2766698

Chataut, R. (2020). *Massive MIMO Systems for 5G Optimization for 5G Massive MIMO System View project*. https://doi.org/10.32545/encyclopedia202006.0016.v2

Dayana R, & KumarR. (2018). Performance Analysis of Universal Filtered Multi-Carrier-Isotropic Orthogonal Transform Algorithm for Next Generation Wireless Networks. In *International Journal of Engineering & Technology*.

Farhang-Boroujeny, B. (2011). OFDM versus filter bank multicarrier. *IEEE Signal Processing Magazine*, *28*(3), 92–112. https://doi.org/10.1109/MSP.2011.940267

Hammoodi, A., Audah, L., Al-Jobouri, L., Mohammed, M. A., & Aljumaily, M. S. (2022). New 5G Kaiser-Based Windowing to Reduce Out of Band Emission. *Computers, Materials and Continua*, *71*(2), 2721–2738. https://doi.org/10.32604/cmc.2022.020091

Jose, F. K., Lolis, L. H., Mafra, S. B., & Ribeiro, E. P. (2018). Spectral efficiency analysis in massive MIMO using FBMC-OQAM modulation. *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, *17*(4), 604–618. https://doi.org/10.1590/2179-10742018v17i41544

Lv, Z., & Li, Y. (2016). A Channel State Information Feedback Algorithm for Massive MIMO Systems. *IEEE Communications Letters*, *20*(7), 1461–1464. https://doi.org/10.1109/LCOMM.2016.2557788

Lynch, P. (1997). *655 The Dolph-Chebyshev Window: A Simple Optimal Filter*.

Nadeem, Q. U. A., Kammoun, A., Debbah, M., & Alouini, M. S. (2015). 3D Massive MIMO Systems: Modeling and Performance Analysis. *IEEE Transactions on Wireless Communications*, *14*(12), 6926–6939. https://doi.org/10.1109/TWC.2015.2462828

Özdogan, Ö., Member, S., Björnson, E., & Member, S. (2019). Massive MIMO with Spatially Correlated Rician Fading Channels. *Journal of Communications*, *67*(5), 1–17.

Sadhana .T and Soundharya .V. (2018). Performance Analysis of UFMC and its Comparision with CP-OFDM. *International Jornal of Engineering and Techniques*, *Vol.4*(2), 776-780,.

Schaich, F., Wild, T., & Chen, Y. (n.d.). *Waveform contenders for 5G-suitability for short packet and low latency transmissions*.

Shreesh, C., & Chopra, S. R. (2018). A review on methods of FBMC and other techniques of massive MIMO. *Proceedings - 2nd International Conference on Intelligent Circuits and Systems, ICICS 2018*, 239–245. https://doi.org/10.1109/ICICS.2018.00056

Singh, B., Shokeen, V., & Asthana, R. (2019). Performance Evaluation of QAM for Improvement of BER. *Wireless Personal Communications*, *109*(1), 77–88. https://doi.org/10.1007/s11277-019-06551-3

Song, H. J., Matsuzaki, H., & Yaita, M. (2016). Sub-Millimeter and Terahertz-Wave Packaging for Large Chip-Width MMICs. *IEEE Microwave and Wireless Components Letters*, *26*(6), 422–424. https://doi.org/10.1109/LMWC.2016.2537789

Sun, W., Liu, C., Qian, M., Chen, Y., & Xu, S. (2021). Joint spectral efficiency optimization of uplink and downlink for massive MIMO-enabled wireless energy harvesting systems. *Eurasip Journal on Wireless Communications and Networking*, *2021*(1). https://doi.org/10.1186/s13638-021-02057-4

Wu, D., Wang, J., Cai, Y., & Guizani, M. (2015). Millimeter-wave multimedia communications: Challenges, methodology, and applications. *IEEE Communications Magazine*, *53*(1), 232–238. https://doi.org/10.1109/MCOM.2015.7010539

Wu, L., Zhang, Z., Dang, J., Zhu, B., Jiang, H., & Liu, H. (2019). UFMC-based interference management for heterogeneous small-cell networks. *IEEE Access*, *7*, 136559–136567. https://doi.org/10.1109/ACCESS.2019.2941995

Zheng, K., Ou, S., & Yin, X. (2014). Massive MIMO channel models: A survey. In *International Journal of Antennas and Propagation* (Vol. 2014). Hindawi Publishing Corporation. https://doi.org/10.1155/2014/848071