Enhancement in the Spectral Efficiency on Universal Filter Multi Carrier for Higher Order QAM

By:SirawAsnake

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We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled" **Enhancement in the Spectral Efficiency on Universal Filter Multi Carrier for Higher Order QAM**" Prepared under our guidance by Siraw Asnake Kifle submitted in partial fulfillment of the requirement for the degree of Masters 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.

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Co-Advisor Signature Date

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Table of Contents

Table of Contents

List of figure

LIST OF TABLES

List of Abbreviation

OFDM……………………..Orthogonal frequency division multiplexing

QAM………………………Quadrature amplitude modulation

5G………………………….Fifth generation

4G………………………....Fourth Generation

SC-OFDMA………………Single-carrier orthogonal frequency division multiplexing Access

UFMC…………………….Universal Filter Multi Carrier

FBMC…………………....Filter Bank Multicarrier

D2D. ……………………..Device to device

OSNR…………………….Optical signal to noise ratio

CP………………………...Cyclic prefix

ICI…………………………Inter-channel interference

ISI………………………....Inter-symbol interference

MCM………………………Multicarrier modulation

LTE………………………..Long-Term Evolution

WLANs…………………...Wireless Local Area Networks

OOB……………..............Out-of-band

DVB-T…………………….Digital video broadcasting-terrestrial

PAPR………………………Peak-to-average power ratio

Abstract

A higher data rate and ultra-reliable along with low latency are the requirement of the 5G (fifth generation) communication system due to enhanced mobile broad band, massive machine type communication. Although OFDM (Orthogonal frequency division multiplexing) waveform is used by 4G (fourth Generation) which is not able to achieve these requirement of the 5G due to side band leakage, high peak to average power ratio (PAPR) and low spectrum utilization. A higher-order modulation technique can increase the data rate but the problem is interference. The interference can be reduced by filtering methods such as matched filtering. So the first part of this work will be focused on the implementation of a filtering operation on the communication system which is using Higher-order QAM. The second phase of this work is the implementation of Higher-order QAM on new generation waveform such as OFDM, Filtered OFDM (F-OFDM), Filter Bank Multicarrier (FBMC), and Universal Filter Multi Carrier (UFMC). In this work, three performance metrics such as spectrum efficiency, PAPR and Bit Error Rate (BER) were studied. The rigorous simulation results show that UFMC provides higher spectrum efficiency due to Sub band filtering compared to other considered waveforms. It has the lead of lowering barriers between sub bands while simultaneously shortening the filter length, making it ideal for brief bursts. In addition to spectrum efficiency, UFMC also provide a slightly better BER and PAPR value (0.003, 0, 0……. and 6.227) compared to F-OFDM (0.1125, 0, 0 ... and 8.894334 and FBMC (0.039094, 0.004732, 0 ... and 7.759556) at SNR >= 25dB for 1024 –QAM .

Keywords: Filtered Orthogonal frequency division multiplexing, Filter Bank Multicarrier, Quadrature Amplitude Modulation, multiplexing, UFMC, M-arry QAM.

CHAPTER ONE

1. Introduction

1.1. Background of the study

Nowadays, the purpose of modulation is to cram as much data as possible into the least amount of spectrum possible. The spectral efficiency (bits per second per Hz) is a measurement of how rapidly data can be transmitted within a certain bandwidth. More bits per symbol can be conveyed if the symbols have a blend of amplitude and phase. Quadrature amplitude modulations have this property (QAM). QAM is spectrum efficient yet difficult to demodulate in the presence of noise. In essence, QAM uses two orthogonal pulse amplitude modulation (PAM) channels to approximately twice the spectral efficiency. [1].

Because of the large range of services and consumers for whom spectrum is required, establishing a uniform criterion for spectrum efficiency consumption is impossible [2].

Satellite broadcast systems, point-to-point satellite systems, terrestrial broadcast systems, terrestrial personal communication systems, terrestrial point-to-point systems, and terrestrial hybrid systems are the six categories in which different efficiency measures can be applied. Communication system traffic is increasing these days. As a result, for the same aim, higher order modulation is necessary.

However, because of the optical signal to noise ratio (OSNR), higher order modulation does not offer efficient long-distance transmission [3]. Various modulation techniques can provide high data rates, improved system capacity, more exposure, bandwidth flexible operations, improved spectral efficiency, short round trip time, small dormancy, low operation cost, multi antenna provision, and seamless integration with the internet and existing generation of communication systems thanks to the efforts of researchers [4]. In communication systems, orthogonal properties can give greater data rates, improved spectrum efficiency, and power reduction [1]. In terms of BER, this suggested work delivers 16QAM, 64QAM, 256QAM, and 1024QAM performance (bit error rate).M-QAM will be used to display the BER on oversampling factors 1, 2, 3, 4, and 5. The binary coding scheme, the gray coding scheme, pulse shaping using a raised cosine filter approach, and error correction using convolution coding are all procedures where M-QAM will be used.For oversampling factors 1, 2, 3, 4, and 5, SNR is also evaluated for 16QAM, 64QAM, 256QAM, and 1024QAM.

The BER for both wireless and wireline communication is:

BER for wireless communication: $\frac{1}{2SNR}$ (1.1)

BER for wire line communication: $Q\sqrt{SNR}$ (1.2)

Where $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-\frac{x^2}{2}}\,dx$ (1.3)

For several wireless communication systems, such as 4G Long-Term Evolution (LTE) [5], Wireless Local Area Networks (WLANs) [6,], and digital video broadcasting-terrestrial (DVB-T) [7], orthogonal frequency division multiplexing with cyclic prefix (CP-OFDM) has been a predominate multicarrier modulation (MCM) technique. Because CP-OFDM systems divide wideband frequency selective channels into numerous parallel narrowband sub channels, they can give robustness to frequency selective channels and use a basic one-tap channel equalization structure. CP-OFDM systems, on the other hand, necessitate the addition of a redundant CP in the time domain to achieve these benefits. Furthermore, it must ensure the frequency domain guard bands in order to avoid excessive out-of-band (OOB) emissions [8]. As a result of the duplicated resources in the time-frequency domain, CP-OFDM systems' spectral efficiency suffers.

Due to various advantages such as ease of implementation, immunity to interference, high data rate, and so on, Orthogonal Frequency Division Multiplexing (OFDM) has been the most appealing for the development of wireless communication systems such as 4G. 5G, on the other hand, will require more from the physical layer than the existing OFDM can provide. As a result, more waveforms have been proposed to address the OFDM issues. We propose to evaluate M-QAM on new generation waveforms for OFDMA, SC-OFDMA, Filter bank multicarrier (FBMC), and Universal-filtered multicarrier in this proposed work (UFMC).

The orthogonal frequency division multiplexing (OFDM) modulation method is currently employed in fourth generation (4G) networks [9–11].To offer reliable transmission and enhance system capacity, OFDM can effectively counteract the multi-path fading channel. Because of the neighboring sub-carriers and symbols, OFDM uses a cyclic prefix (CP) and a guard interval between the OFDM symbols to avoid inter-channel interference (ICI) and inter-symbol interference (ISI). Furthermore, OFDM has huge side lobes [12], a complex power amplifier design due to the high peak-to-average power ratio (PAPR), and synchronization faults in data aggregation, making it unsuitable for cognitive radio and IoE networks [13]. This prompted researchers to create and propose robust modulation formats that would meet the needs of emerging wireless networks [14–17].

1.2. Statement of the Problem

- A higher-order modulation technique can increase the data rate but the problem is interference.
- OFDM technique spread side lobes which reduces spectral efficiency that is is not good for 5G communication system.
- OFDM suffers from a high peak-to-average power ratio (PAPR) and data aggregation synchronization issues, making it unsuitable for cognitive radio (5G wireless communication systems) and low spectrum utilization.

1.3. Objective

1.3.1 General objective

The main goals of this thesis are to provide numerous accesses for wireless communication systems with faster data speeds while reducing out-of-band radiation, increasing spectral efficiency, and simplifying the system.

1.3.1 Specific objective

- To study and implementation of M-QAM (16-QAM, 64-QAM, 256-QAM, 1024-QAM) on various communication system.
- Performance evaluation of M-QAM on various noisy conditions.
- Reduction of Interference generated by higher-order QAM
- Evaluation of M-QAM on new generation waveform i.e. OFDMA, F-OFDMA, FBMC, and UFMC

1.4. Significance of the study

The fifth generation (5G) communication networks have developed needs for high speed, low latency, high spectrum efficiency, and other features in response to the growing demand for communication quality [18]. As a result, many people believe that the final 5G waveform solution would contain an adaptive solution, which implies that the best waveform for any given situation will be used. The multiple access technology that is employed today is a major component of the cellular communication system. As a result of its capacity to minimize intersymbol interference (ISI) and interchannel interference (ICI), multicarrier modulation (MCM) has become a research hotspot in the communication sector (ICI).

Orthogonal frequency division multiplexing (OFDM) is a common MCM technique that has been employed in fourth-generation (4G) communication networks [19]. Despite its many advantages, OFDM is still unable to meet the needs of 5G networks [18]. New 5G waveforms are being examined and assessed for use with the new system, thanks to the higher level of processing that will be accessible. Scholars from all around the world have looked at additional MCM waveforms, such as the well-known modulation techniques of filter bank multicarrier (FBMC), generalized frequency division multiplexing (GFDM), and universal filtered multicarrier (UFMC) [20]. Each has its own set of benefits and drawbacks [21]. The modulation techniques employed in future 5G networks are expected to have a considerable impact on overall performance and will play a significant part in deciding the performance and complexity of communication systems; however, no one technique is likely to meet all of the requirements.Academia is working on different joint projects like METIS [22] and 5G NOW [23] to help advance 5G standardization.

1.5. Scope and Limitations of the Study

Different topologies, modulation symbol formats, and/or sizes are included in the waveform network progression communications standards. Frequency Division Multiplexing (FDM), Orthogonal Frequency Division Multiplexing (OFDM), and advanced Cyclic Prefix–OFDM are all instances of frequency division multiplexing (CP-OFDM). As a Long-Term Evolution (LTE) technology, the CP-OFDM has been commercially used in 4G. CP-OFDM, on the other hand, was unable to meet the demands of various numerologies and communication scenarios in LTE. Other methods of multiplexing include Generalized Frequency Division Multiplexing (GFDM), non-orthogonal multiple access (NOMA), Filter Bank Multicarrier (FBMC), filtered OFDM (f-OFDM), and Universal Filtered Multicarrier (UFMC), sometimes known as universal filtered OFDM (UF-OFDM).The UFMC is thought to be the best waveform for 5G technology.

Because of the time-domain coherence of subcarriers, multicarrier modulation methods have a high Peak to Average Power Ratio (PAPR). High PAPR causes the power amplifier to enter the nonlinearity area, resulting in OOB emission, IB distortions, and extended word length. The digital to analogue converter's lengthy word length is a critical issue that drastically lowers battery life. To lower the PAPR in the waveform, various techniques are presented. The simplest non-linear time-domain location approach is amplitude clipping. The OOB emission and IB distortion are reduced by amplitude clipping, but the BER is increased. Another time-domain-located strategy for lowering PAPR is commanding.

It compresses the signal's high peaks and enlarges the signal's minor peaks while also increasing the BER. Frequency-domain strategies such as Tone Reservation (TR) and Tone Injection (TI), on the other hand, aid PAPR reduction. TR and TI, on the other hand, use a lot of power and processing time to identify the best cancellation tones. Another frequency-domain solution for solving the PAPR problem is Multiple Signal Representation (MSR). The MSR is a probabilistic approach for creating and transmitting multiple copies of original data vectors, which lowers the PAPR but raises the BER.

1.6. Thesis organization

This thesis is divided into five chapters, each of which is discussed in turn:

Chapter 1 discusses the introduction parts which consists background, statement of problem, objectives, general objective and specific objectives, significance of the study, scope of the study and limitation of the study. Chapter 2 presents the literature review and related works which explain the concept of multicarrier modulation techniques such as OFDM, F-OFDM, FBMC and UFBM using M-QAM. Chapter 3 presents the methodology of the study in terms design and simulation of higher order QAM on OFDM, FBMC and UFBM using MATLAB software. Chapter 4 discusses the simulation result and analysis of OFDM, FBMC and UFBM using BER, PAPR and PSD as comparisons parameter And finally conclusion and recommendation of the thesis is discussed.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Future wireless applications will necessitate high data rates. Dealing with an unreliable wireless channel while communicating at a higher data rate isn't easy. The concept of multi-carrier modulation has lately surfaced as a way to mitigate the malevolence of wireless channels while also providing high data rate communications. [24] According to Nyquist criterion, more bandwidth is necessary to accommodate a greater data rate. When the signal bandwidth exceeds the coherence bandwidth, however, the channel becomes time dispersive. Time dispersion is a signal distortion that is exhibited in the time domain by the spreading of symbols, also known as delay spread, and is reflected by the inter-symbol interference (ISI) event. [25]. the inverse proportionality relationship between coherence bandwidth and delay spread reflects this in the frequency domain as well. In other words, the shorter the coherence bandwidth and hence the better the channel frequency selectivity, the higher the delay spread.

The coherent bandwidth of the channel is always smaller than the signal bandwidth for broadband transmission. In such circumstances, the frequency selectivity effect, which has a random pattern at any given time, cannot be easily prevented. When the channel introduces temporal dispersion and the delay spread is greater than the symbol period, this fading occurs. Because the fading characteristics are variable and may not be easily foreseeable, frequency selective fading is difficult to adjust. At the receiver, a very complicated structure is required, making equalization and channel estimation techniques computationally expensive [26]. The fading will be flat if there is no dispersion and the delay spread is less than the symbol period. With a simple equalization, you can estimate and adjust for practically flat fading [27].

Single-carrier transmission suffers from the ISI problem at very high data rates. Multicarrier transmission [28] has been proposed as a solution to this problem. Multicarrier modulation is a type of Frequency-Division Multiplexing (FDM) in which data is sent over many narrowband carriers at different frequencies. Guard bands separate subcarrier signals in a traditional FDM system. As illustrated in Figure 2.1, multicarrier modulation divides the entire frequency band into too many subcarriers, and high data streams are divided into too many low-rate data streams to broadcast in parallel on subcarriers [24].

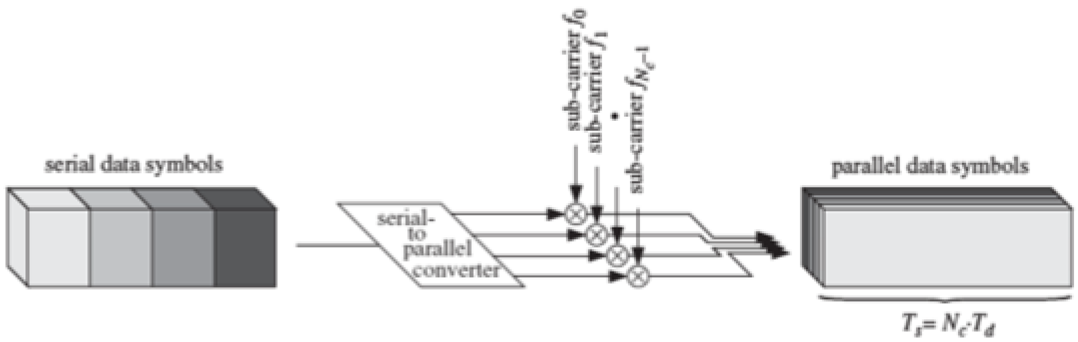


Figure: 2.1: General block of multicarrier modulation with 4 subcarriers [24]

The parallelization of data symbols across numerous subcarriers results in a symbol duration that is quite long. Each symbol has a narrowband but a longer time duration here. This clearly demonstrates that the delay spread has an ISI effect on the receiver. This can be described as the multicarrier technique converting the channel to a flat fading channel that can be easily approximated [29].

MOFDM is a popular multicarrier modulation technique used in wireless communication. With the support of associated technologies and procedures, it has a clearly identified capacity for usage in a more sophisticated manner [30]. However, because to specific restrictions and forthcoming requirements, the search for alternate transmission strategies for physical layer communication has been finished [31]. FBMC and UFMC can be proposed as prospective candidates for overcoming some of the limitations associated with OFDM.

This chapter goes through OFDM, UFMC, and FBMC techniques in depth, including their evolution, basic formulation, and signal models employed in this study. Each modulation approach is well explained. The fundamental principle, system block diagram, and mathematical formulation are also discussed.

2.2 Related works

Ghorpade et.al [30] Inside this article, you will learn how to implement an OFDM transmitter and receiver in MATLAB. OFDM is designed to deal with the multipath propagation effect by dividing the wideband frequency's broad fading channel into some narrow band flat fading channels. To avoid inter-carrier interference, OFDM uses the sub-carriers' guard bands to keep them apart. When 64 subcontractors are used, processing time and complexity are generally reduced. Increase spectral efficiency and decrease peak to average power ratio by using power amplifiers, and reduce PAPR by using other methods such as clipping, scrambling, peak cancellation, and so on. As a result, it dealt with the issue of multipath fading.

The FBMC techniques used to increase the bits rate by reducing the guard interval and when cyclic prefix is not present in OFDM as needed as defined by Lalit Chettriet.al [31]. The future FBMC must increase efficiency and optimize bandwidth utilization. The first step in the FBMC OQAM post-processing process is pattern multiplication. In addition, OQAM conversion from real to complex is performed after post-processing, and a single complex symbol is valued in this symbol with two true values. However, the conversion lowers sampling rates. The full model of FBMC is planned and simulated through the so-called Systemvue2013.01 software. Random bits are utilized before these in this approach because the input pulse can be converted to a number.

The Virtual Amplification model could be used to generate the baseband's digital amplification pulse, as well as the basic amplification systems. As a result, the modulation scheme 16QAM is utilized. The equalization on the receiver side is utilized to solve the overlapping difficulties in this case.

The high PARP is the main issue Hanwanget.al [32] has implemented in all multicarrier communication systems. The following strategies were previously utilized in OFDM to minimize PARP: SLM, PTS scheme, and TR scheme, but these schemes were not applicable to FBMC due to the differing FBMC structure. A hybrid technique for FBMC / OQAM signals that relies on the multi data block approaches PTS and TR to minimize the PARP. This is an extremely effective way for neutralizing signal peaks.

Behrouz Farhang-Boroujeny et.al suggested the idea of the various multicarrier techniques [29]. Second, OFDM (orthogonal division frequency multiplexing) in wireless communication recommended addressing ISI. It divides the available bandwidth among a number of subcarrier companies. Using filter banks, there existed another approach for synthesizing and analyzing multi-carrier signals prior to the OFDM method.

Filter banks are frequently suggested for modulating CMT and VSB. In VSB (Vestigial Side-Band Modulation), the signal bandwidth range is separated into two classes: baseband signal and wideband signal. The first half of the baseband signal is used to modulate a complex sine wave at a positive frequency, while the second part is used to modulate a complex sine wave at a negative frequency. The multicarrier approach is effective for coping with limited frequency channels when the gain varies across the frequency band, causing ISI and ICI. To overcome this difficulty with a multicarrier system, use a channel equalization method. With less complexity and network expense, centralized non-equalization is being used to balance the network disadvantage between different users.

Because FBMC uses prototype filters to evaluate the moment-frequency window for each subcarrier, it has a stronger pre-equalization than OFDM. As a result, the unwanted side lobes will be reduced. It enables the system to integrate asynchronous CCs without the need for multiple clients, providers, or locations. The MMSE is employed to obtain the pre-equalization in this case. Before pre-equalization, there is often an underlying theoretical conflict between neighboring subcarriers and IDs, which is a drawback of using FBMC .This makes estimating networks by preamble definition problematic. Liu Xu et.al[19] proposed a comparison of the efficiency and performance of FBMC and OFDM with centralized pre-equalization and without centralized pre-equalization. Chanhong Kim's description of the QAM FBMC principle (Quadrature amplitude multiplexing-filter multicarrier bank)

2.3 OFDM Transmission

Another sort of multichannel system is an OFDM transmission technique. For wideband digital communication, FDM has been accepted for wireless protocols like IEEE 802.11a.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 use OFDM on the physical layer.

2.3.1 Basic principle of OFDM

Using orthogonal subcarriers, the OFDM technology enables for concurrent transmission of several data streams. Figure 2.2 depicts a general overview of the OFDM system, and the signal processing of the OFDM trans-receiver is expressed as follows: Quadrature amplitude modulation (QAM)/ Phase-shift keying is used to convert digital data bits to complex symbols (PSK). By using a serial to parallel converter, these data symbols are translated to N streams, which correspond to subcarrier frequencies. The streams were then sent through an inverse fast Fourier transformation (IFFT) block to construct a temporal sequence. The complex values modulating the subcarriers in each symbol period in an OFDM signal are statistically independent of each other and orthogonal. The orthogonality of sub-carriers will prevent interference between the overlapping carriers that are closely spaced. The spectrum of each sub-carrier has a null at the center frequency of the other carriers in the system due to their orthogonal nature, resulting in no interference between them. Because each subcarrier has a restricted bandwidth, it has a low symbol rate and consequently a high tolerance for multipath delay spread.

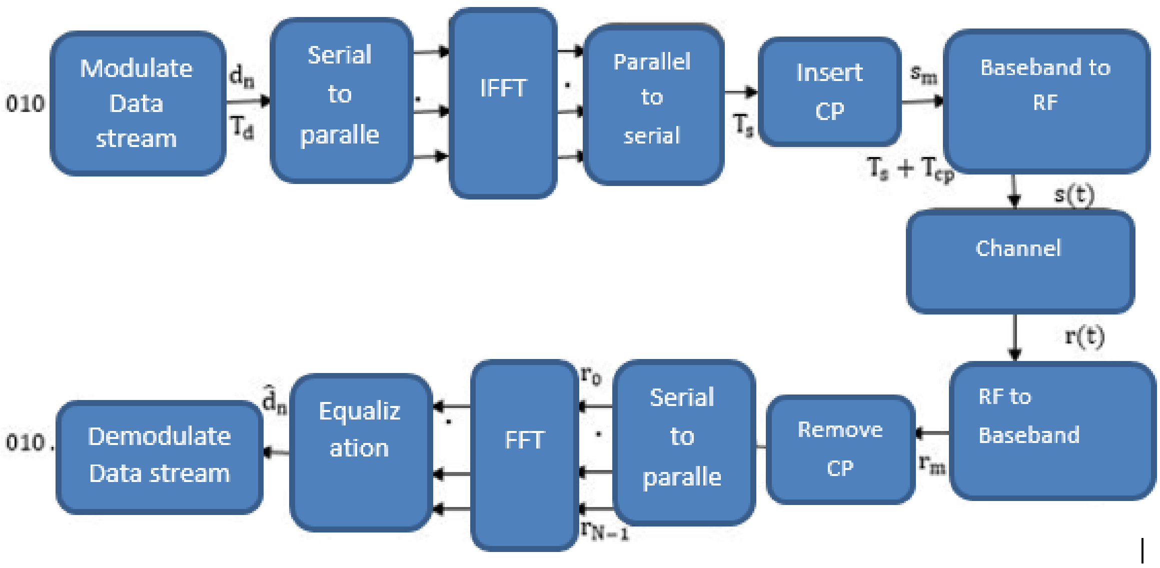


Figure: 2.2: Physical layer block diagram of OFDM[33]

To cause significant ISI, be exceedingly lengthy. This also allows the signal to be easily isolated at the receiver end. The cyclic prefix (CP) in front of the sequence of OFDM signal samples at the output of IFFT is extended by the final sample of each OFDM symbol being sent before the next symbol. This comprises of a handful of the sequence's repeated samples collected from the end. This CP is introduced at the transmitter and removed at the receiver, resulting in a cyclic (not linear) convolution of the broadcast signal and the channel impulse response at the FFT's input. As a result, ISI is removed (there is no overlapping of the received symbols), even if the symbols may still be corrupted by the channel.

Finally, a Digital-to-Analog (D/A) converter converts the receiving signal to an analog signal, which is then supplied to the radio frequency (RF) stage and transmitted. The first CP samples are destroyed at the receiver because they are affected by ISI, while the succeeding OFDM samples are maintained for further processing. In the FFT block, the received signal's time-domain samples are demodulated. ISI is abolished since the CP is applied at the transmitter and removed at the receiver, and the OFDM equalizer consists of N, one-tap equalizers that are designed to equalize the frequency-selective channel's distortions to different subcarriers.

2.3.2 Guard Interval/ Cyclic Prefix (CP):

ISI is a common difficulty in high-data-rate communication because the time length reduces as the data rate increases. Self-interference develops as a result of the multipath delay spread, which is wrongly decoded at the receiver. The bare minimum to avoid ISI is to keep the time duration longer than the channel's maximum delay [33]. One of the major disadvantages of single-carrier transmission is this. To avoid this problem, a guard interval can be added as an overhead that can be removed later and the data recovered. The long guard interval used in OFDM results in a high level of robustness against multipath delay spread. Before the information from the current symbol is received, the guard interval enables time for the multipath signal from the preceding symbol to pass away. As a result, the multipath effects of one symbol cannot conflict with those of another.

The CP is a cyclic extension of each OFDM signal generated by increasing the duration of each OFDM symbol while maintaining sub-carrier orthogonality. As a result, the CP duration (in samples) should be equal to one sample less than the channel impulse response (in samples). Each guard interval's length must be greater than the projected delay spread,

$$\mu \geq \left\lceil \frac{\mathcal{T}_{maxN}}{T_s} \right\rceil \tag{2.1}$$

is the required discrete length of CP samples in order to prevent ISI [11].

2.3.3 Mathematical Description of OFDM

The mathematical expression of OFDM signal resulting from modulated N subcarriers can be expressed as

$$S(t) = \sum_{n=0}^{N-1} d_n e^{j2\pi fnt} \qquad 0 \leq t \leq T_s \tag{2.2}$$

Where dn is complex data symbol which modulate the n-th subcarrier at the modulation interval, while Ts is the time duration of an OFDM symbol which is Ts = NTd and Td is the serial symbol duration. The orthogonality of subcarriers is ensured, if the distance between neighboring subcarrier frequencies equals and subcarriers located at

$$f_n = \frac{n}{T_s} \qquad n = 0 \ldots\ldots\ldots\ldots\ldots\ldots N-1$$

The output from the IFFT and after this there is cyclic prefix extension of this samples result for

$$S_m = \frac{1}{N}\sum_{n=0}^{N-1} d_n e^{\frac{j2\pi nm}{N}} \qquad m = -\mu \ldots\ldots\ldots\ldots\ldots\ldots N-1 \qquad (2.3)$$

The discrete length of the cyclic prefix is described in the preceding subsection. This sequence is fed into a digital-to-analogue converter, which should produce the signal waveform s(t)with rising duration 'Ts as the output. The signal is up-converted and sent to the channel as an RF signal.

The received signal waveform r(t) formed by convolution of s(t) with the channel impulse response h(t) and addition of a noise signal n(t) is the channel output after RF down-conversion.

$$r(t) = \int_{-\infty}^{\infty} s(t-\mathcal{T})h(\mathcal{T},t)d\mathcal{T} + n(t) \qquad (2.4)$$

This was fed through an analogue-to-digital converter, which produced a r(t) sampled output sequence at 1/Td. The first samples of the received sequence are deleted before multi-carrier demodulation because ISI is believed to be present only in the first samples. The ISI-free section m = 0 ... N-1 A FFT is used to demodulate N-1, which is a multi-carrier signal. The multi-carrier demodulated sequence with N complex-valued symbols is the FFT's output.

$$S_m = \frac{1}{N}\sum_{n=0}^{N-1} d_n e^{\frac{j2\pi nm}{N}} \qquad n = 0 \ldots\ldots\ldots\ldots\ldots\ldots N-0 \qquad (2.5)$$

Because the cyclic prefix eliminates ISI, each sub-channel can be considered independently.

Furthermore, when the fading on each sub-channel is assumed to be flat and ISI is removed, the frequency domain representation yields a received symbol dn as follows:

$$d_n = H_n d_n + N_n \qquad (2.6)$$

The flat fading factor is Hn, while the noise of the nth sub-channel is Nn. The complex data symbols are fed to the QAM demodulator after parallel to serial conversion of the output from the FFT, and the transmitted bits are estimated.

2.4. FBMC Transmission

Another type of multi-carrier modulation is FBMC. [34] Introduced the first advances in the FBMC system. Chang, in particular, proposed employing Vestigial Side-band modulation (VSB) to transfer asset of parallel (real valued) pulse amplitude modulated (PAM) symbols [35]. On the other hand, Saltzberg has built on Chang's work and presented a new approach called Staggered Modulated Multitone (SMT) [34]. The three families of multicarrier modulation techniques that FBMC approaches belong to are listed below.

1. **Filtered Multitone (FMT) :**
   FMT is a type of FBMC in which subcarriers are separated by guard bands in the middle, resulting in bandwidth waste. It uses a well-designed filter to resolve inter-channel interference [36]. Unlike OFDM, the subcarrier channels in FBMC-FMT do not overlap with adjacent subcarrier bands, making it less bandwidth efficient than OFDM. However, unlike OFDM [36], it does not require a guard interval, enhancing overall energy efficiency. Because there is no overlap between subcarriers in FBMC FMT, it is based on traditional frequency division multiplexing (FDM).
2. **Cosine-Modulated Multitone (CMT):**

   This mode is an early FBMC modulation technology that has recently been used in the field of digital subscriber line (DSL) wireless applications. CMT system in which a parallel set of data symbols with pulse amplitude modulation (PAM) are transmitted, with only the real part of the symbols constellation. Furthermore, the PAM symbol sequences are routed via a spectral overlap filter bank. As a result, the filter design constraints are reduced. Vestigial side-band (VSB) modulation is used on each subcarrier to maximize the system's bandwidth efficiency. The cosine modulated filter bank, which has a high bandwidth efficiency as well as the ability to detect blind signals. The adjacent subcarriers, however, experience a 90-degree phase shift [37].

3. **Staggered Multitone (SMT):**
   SMT, often known as offset QAM (OQAM), is a form of filter bank multicarrier that is quite similar to the CMT design but has several advantages. SMT entails sending a sequence of complex-valued data symbols (generally QAM symbols) with their real

and imaginary parts separated and time staggered by one half of the symbol duration, resulting in OQAM symbols. In OQAM-FBMC, which transmits OQAM symbols instead of QAM In the time domain, the data symbols are spaced at T/2, whereas the subcarriers are spaced at 1/T along the frequency axis. As a result, the symbol rate in SMT can be doubled while the symbol spacing is cut in half. For a fixed filter length and number of subcarriers, OQAM-OFDM has the maximum stop-band attenuation when compared to CMT and FMT [38]. We are more interested in OQAM-FBMC in this thesis since the FMT approach does not reach maximum bandwidth efficiency [38]. OQAM-FBMC overlaps subcarriers in the frequency domain and gives the highest bandwidth efficiency.

2.4.1 Basic Principle of FBMC

The frequency spreading filter bank multicarrier (FS-FBMC) and the poly-phase network filter bank multicarrier are two types of FBMC implementations (PPN-FBMC). In this section, we talked about them. Figure 2.3 and Figure 2.4 show the block diagram of the FBMC system. OQAM symbols are filtered in the frequency domain in FS-FBMC. The result was then fed into IFFT, which performed KN-point IFFT before performing an overlap and sum operation [33]. Where K is the prototype filter's overlapping factor. A sliding window on the receiver side picks KN points for each sample. The FFT size of the KN point is then applied, followed by equalization and prototype filtering. For PPN-FBMC, however, the OQAM symbol is fed into an N-point IFFT and then into a poly phase network for filtering.

Filtering is applied before N-point FFT and multi tap at the receiver.

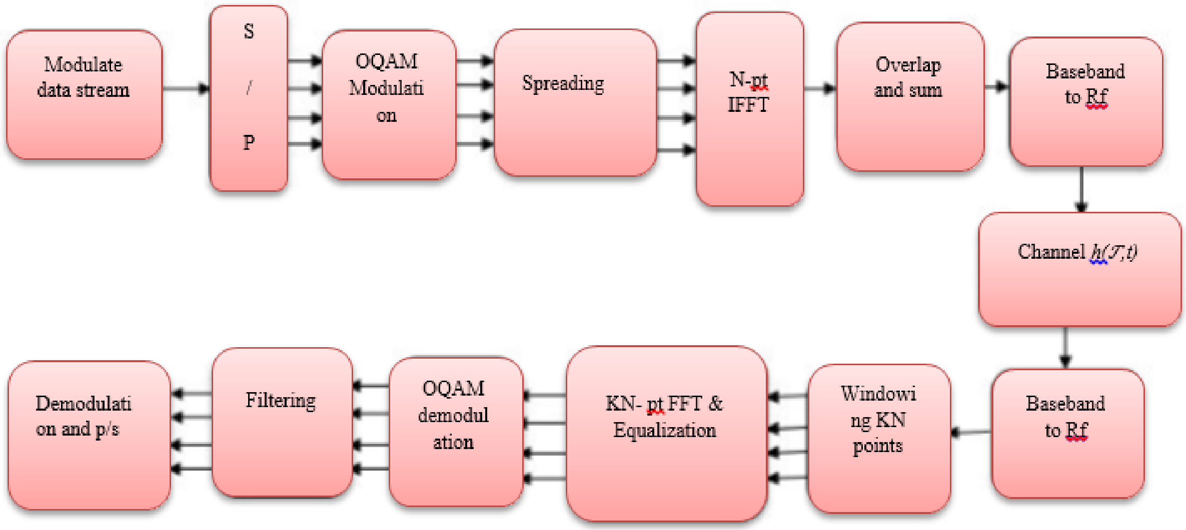


Figure: 2.3 Physical layer block diagram of FS-FBMC[33]

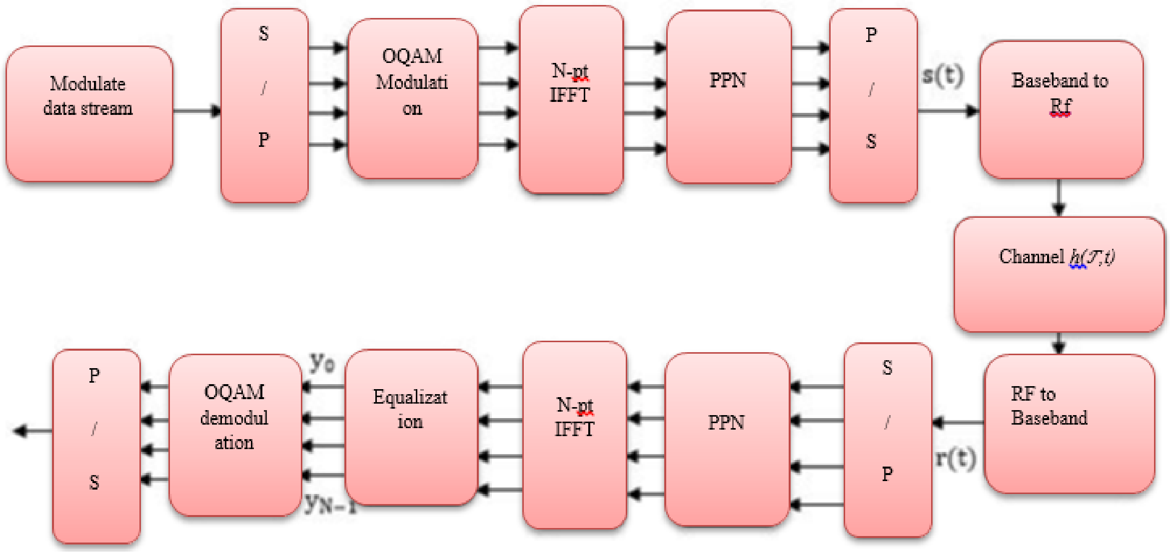


Figure: 2.4: Physical layer block diagram of PPN-FBMC[33]

The equalization process is carried out on a subcarrier basis [15]. OQAM pre-processing, filter banks, and OQAM post-processing are the three main processing stages of FBMC. A filter bank is a system in FBMC that consists of a group of filters that process a common input or result into a common output. The analysis filter bank (AFB) and the synthesis filter bank (SFB) are the two main types of filter banks (SFB). AFB is used to analyze the input signal based on the filter properties. SFB is used to filter individual signals before adding them together to create a new composite signal. SFB and AFB [31] were implemented using an IFFT followed by a poly phase network structure or a poly phase network followed by an FFT.

The filter bank's main function is to adjust the frequency response of the transmitted signal. As a result, various mechanisms for filter design have been presented. The filter proposed by the Physical layer for dynamic spectrum access (PHYDYAS) projects [32] is used in this thesis. Complex modulation is used to design the N-sub channel filter. This means that a frequency shifted version of the prototype is used to find the rest of the sub channel filters. The essential concept in [10] is to create the Nyquist filter using the frequency-sampling technique. The transmit filters are modulated by carrier frequency fn and are based on a specially built prototype filter pT(t). A time and frequency shifted variation of the prototype filter pT is the basic pulse gn (t)

$$g_n(t) = pT(t)e^{j2\pi n\Delta f t + j\emptyset n} \quad (2.7)$$

pT(t) is a prototype low pass filter with a length of KN, f is subcarrier spacing, and n is phase difference. The filter's impulse response is therefore given by

$$g[m] = 1 + 2\sum_{i=1}^{K=1}(-1)^i P_i cos\left(\frac{2\pi k}{NK}m\right) \qquad g[0] = 0 \tag{2.8}$$

The equation yields the frequency response of the filter with N subcarriers.

$$G(f) = \sum_{i=K+1}^{K-1} P_i * \frac{sin\left(\pi\left(f - \frac{i}{NK}\right)NK\right)}{NKsin\left(\pi\left(f - \frac{i}{NK}\right)\right)} \tag{2.9}$$

Where Øn is phase, Δf is subcarrier spacing, ¯ Pi is filter coefficient, and K is the temporal overlapping factor that characterizes the prototype filter, with K= 2, 3, 4,... This regulates how many symbol blocks are superimposed on top of one another. It was determined to employ an overlapping factor of 4 for FBMC [32]. ¯ Pi is the filter coefficient for a filter length of

Table 2.1: PHYDYAS filter coefficient for K=4 [32]

Filter coefficient	P_0	P_1	P_2	P_3
value	1	0.97195983	0.70710678	0.23514695

Lp = NK and K=4 given by Table 2.1.

The main difference between OQAM and FBMC is that OQAM data symbols are transmitted instead of QAM symbols. OQAM is used in conjunction with Nyquist constraints on the prototype filter to ensure orthogonality (in the real field) between adjacent symbols and adjacent carriers while maximizing spectral efficiency [32]. Figure 2.5 shows the OQAM pre/post-processing block in action. OQAM preprocessing staggered the QAM complex symbol and converted it to real symbols. Assume the incoming QAM modulated signal is cn,m. Two new symbols, dn,2m and dn,2m+1, are formed by separating the real and imaginary portions. The second action is then multiplied by n,m.

The value of n,m for each subcarrier's index is different, as described in [14]. Even and odd numbered sub channels have different conversions.

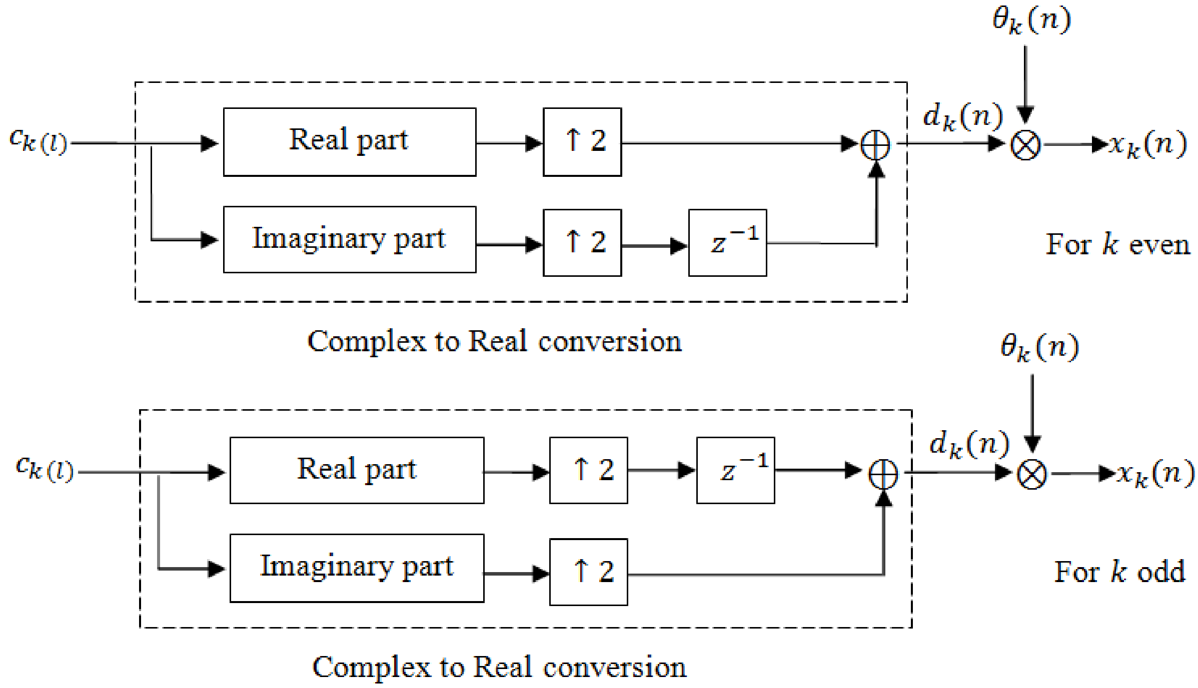


Figure 2.5: Block diagram of the OQAM Symbol arrangement and demodulation process in FBMC-OQAM[33]

$$\theta_{n,m} = \begin{cases} 1, j, 1, j, \dots \dots \dots . \, Even\ subcarrier\ index\ n \\ j, 1, j, 1, \dots \dots \dots . . \, odd\ subcarrier\ index\ n \end{cases} \tag{2.10}$$

The receiver receives the inverse of this operation, which is post-processing. Take the real part of the incoming sequence and multiply it by the conjugate of n,m. The data is then converted to complex data, with two consecutive real-valued symbols (one multiplied by j) forming the de-staggering complex value data cn,m. To maintain the bit rate in FBMC, the real to complex conversion reduces the sample rate by a factor of two.

2.4.2 Mathematical description of FBMC

For the sake of simplicity, we solely consider baseband signals and ignore radio-frequency (RF) chains. The FBMC's baseband sent signal can be expressed in a general way.

$$s(t) = \sum_{m=-\infty}^{\infty} \sum_{n=0}^{N-1} d_{n,m} g_{n,m}(t) \tag{2.11}$$

The complex symbol modulated by the nth subcarrier during the symbol time index m is denoted by dn,m, and the synthesis basis is denoted by gn(t). The symbol duration is cut in half for OQAM-FBMC, and 'T = T/2, where T is the QAM symbol duration.

$$g_{n,m}(t) = pT\left(t - m\frac{T}{2}\right)e^{j2\pi\Delta f t}e^{j(m+n)\frac{\pi}{2}} \tag{2.12}$$

Finally, OQAM- FBMC baseband modulated signal can be expressed as:

$$s(t) = \sum_{m=0}^{\infty} \sum_{n=0}^{N-1} d_{n,m}^{R} g_{n,2m}(t) + d_{n,m}^{I} g_{n,2m+1}(t) \tag{2.13}$$

Where d^Rn,m and d^In,m are the real and imaginary part of dn,m which conveyed by the subcarrier index of n during symbol time of index m.

At the receiver, the analysis filters are based on a specially-designed prototype filter pR(t), the impulse response of analysis filter given by

$$g_k^*(t) = P_R(t)e^{-2\pi jk\Delta f t - j\emptyset_n} \qquad k = 0,1 \ldots . N-1 \tag{2.14}$$

For mathematical analysis for now, ignoring channel impairments, the input signal at the AFB equals the transmit signal of the SFB which is in distortion free noiseless channel.

After the incoming signal r(t) passes through filter, the continuous time output signal can be calculate

$$y_k(t) = g^*{}_k(t) * r(t) \tag{2.15}$$

$$y_k(t) = \sum_{m}^{\infty} \sum_{n=1}^{N-1} d_{n,m} P_R(t) * P_T(t - mT)e^{-2\pi jk\Delta f t - j\emptyset k}e^{2\pi jn\Delta f(t-mT) + j\emptyset_n} \tag{2.16}$$

$$y_k(t) = \sum_{m}^{\infty} \sum_{n=1}^{N-1} d_{n,m} P_R(t) * P_T(t - mT)e^{j2\pi(n-k)\Delta f t + j(\emptyset_n - \emptyset_k)} \tag{2.17}$$

In the temporal domain, the prototype filters are designed to ensure that the output signal does not carry ISI to its nearby symbols. Except for the original, the composite impulse response should be zero at all sampling periods:

$$P_R(t) * P_T(t)|t_s = iT \begin{cases} 1, & i = 0 \\ 0, & i \neq 0 \end{cases}$$

Where t_s = iTis the sampling point at time axis. The demodulated signal at n-subcarrier and m-th symbol can be expressed as;

$$d_{n,m}^{R} = R_e\left\{\int s(t)g_{n,2m}^{*}(t)dt\right\} \tag{2.18}$$

$$d_{n,m}^{I} = R_e\left\{\int s(t)g_{n,2m+1}^{*}(t)dt\right\} \tag{2.19}$$

2.5 UFMC Transmission

The EU-funded 5G NOW research project [27] [25] proposed UFMC as a multicarrier modulation standard. The UFMC technique is based on the frequency division multiplexing (FDM) principle, in which the input data stream is divided into several lower rate sub-streams. UFMC is a type of sub-band altering-based waveform described in [33], in which the altering operation is applied to a group of consecutive subcarriers rather than per subcarrier altering as in FBMC.

2.5.1 Basic principle of UFMC

The UFMC system model is shown in Figure 2.6. B sub-bands are formed from the overall bit streams. These grouped bits are modulated using the QAM or PSK modulation formats before being translated into parallel streams using a serial to parallel converter. A frequency block specific IFFT module converts subcarriers from frequency domain to time domain in frequency block B. The signals are then filtered using a filter length of L. Filtering reduces out-of-band leakage in the frequency domain significantly. This reduces detrimental interference from surrounding resource block sub channels, which eliminates out-of-band emissions.

We employ the Dolph-Chebysheve filter for UFMC, as proposed in [33], which gives a technique for developing UFMC. The size of the sub-band, or the number of carriers in the sub-band, determines the length of the filter. Given a specific side lobe height, the Chebyshev window minimizes the main-lobe width. It has an equi-ripple habit, which means that all of its side lobes are the same height. Because of the linear convolution of IFFT outputs, the UFMC symbol length is N + L1 samples.

The guard intervals were dropped in few prior [22, 25] articles. In the event of extreme multi-path, this affects performance since the channel's temporal dispersion cannot be compensated [27]. In another piece of paper, there is a block with an extra L-1 length zero padded (ZP). To deal with the temporal dispersion, each UFMC block has a zero-padded or guard interval.

When compared to OFDM, this adds some extra time overhead, but it allows for ideal channel time dispersion mitigation using a simple 1-tap frequency domain equalizer (FDE).

To build a UFMC waveform, filtered time-domain data from each frequency block is added at the end. As a result, unlike OFDM, where a single joint IDFT is conducted by combining all frequency blocks, individual IDFT operations on each frequency block are required, as well as windowing for interference reduction. After serial to parallel conversion, each UFMC symbol must be demodulated using a 2N-point FFT at the receiver. FFT is followed by an equalizer, as well as a time synchronization block that can appropriately estimate the delay for FFT.

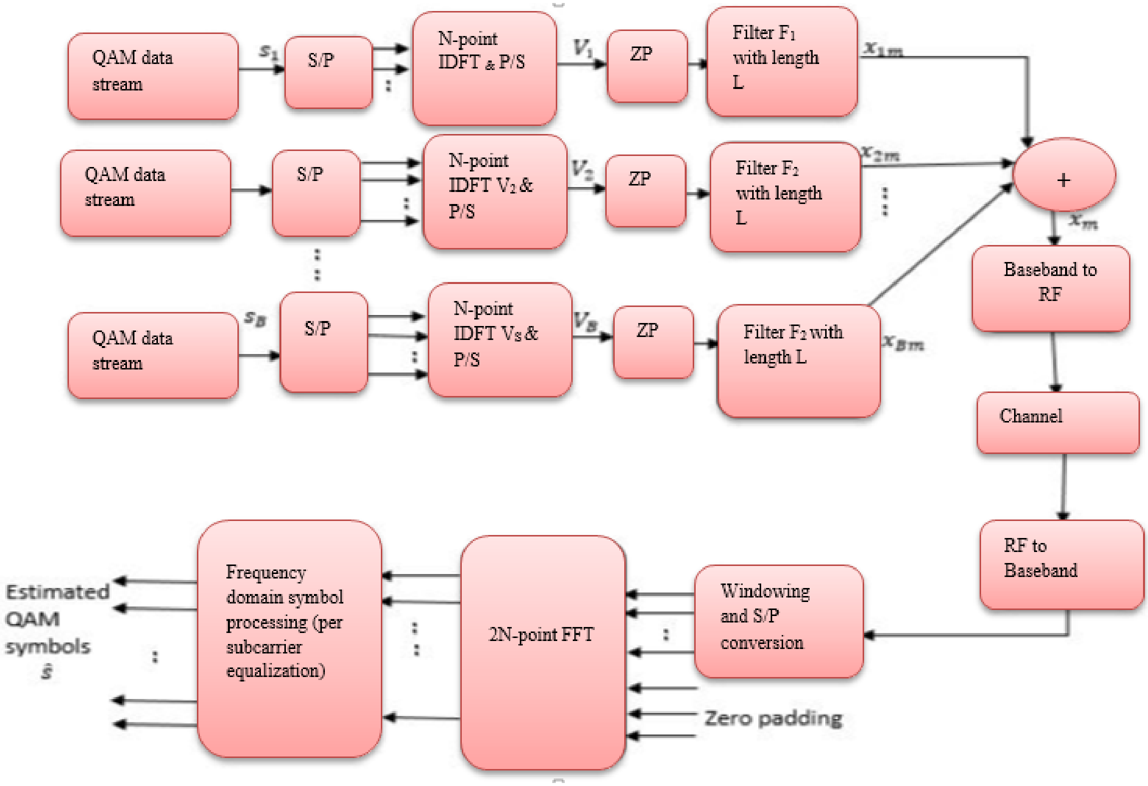


Figure: 2.6: Physical layer block diagram of UFMC[33]

2.5.2 Mathematical model of UFMC

Assume that the UFMC transmit signal is segmented into B sub-bands and has N subcarriers. N/B subcarriers are present in each subband. A set of constellation QAM mapped symbols S is sent into the UFMC waveform generating block. Each frequency block S is made up of p sub carriers, and the symbols S are separated into frequency blocks S. Then, if B is the number of frequency blocks, The IDFT sub matrix (each of dimension NxP) is used to process the B data vectors. After that, each subband is filtered with an L-length subband filter, and the responses from the various subbands are totaled.

For filtering operations, many types of filters with dimensions ((N+L-1)x N) may be used [28]. Fi is a Toeplitz matrix that performs linear convolution and is made up of the filter impulse response. The filter utilized for UFMC is the Chebysheve filter, which is provided by:

$$F_{i,l} = \frac{\cos(Lcos^{-1}\left[\beta coos\left(\frac{\pi l}{L}\right)\right])}{cosh[Lcosh^{-1}(\beta)]} \tag{2.20}$$

where

$$\beta = cosh\left[\frac{1}{L}cosh^{-1}(10^{\alpha})\right]$$

Where α represents the side lobe attenuation. Instead of working between subcarriers, side-lobe suppression now operates between resource blocks. The filter length and FFT size determine the symbol duration of N+L1 samples. The discrete time signal that will be translated to analog domain and broadcast over radio waves is written as

$$x_m = \sum_{i=1}^{B} F_i V_i S_i \tag{2.21}$$

$$x_m = \sum_{i=1}^{B} F_i \left(\sum_{n=0}^{N-1} S_{i,n} e^{\frac{j2\pi n}{N}}\right) \tag{2.22}$$

$$x_m = \sum_{i=1}^{B}\sum_{l=0}^{L-1}\sum_{n=0}^{N-1} S_{i,n} e^{\frac{j2\pi n}{N}} F_i(l) \tag{2.23}$$

This sequence is sent into a digital-to-analogue converter, which should produce the signal waveform x(t) with a duration of N + L1. The signal is up-converted and sent to the channel as an RF signal.

The received signal waveform y(t) formed via convolution of x(t) with the channel impulse response h(t) and addition of a noise signal n(t) is the channel output after RF down conversion.

$$y(t) = \int_{-\infty}^{\infty} x(t-\mathcal{T})h(\mathcal{T},t)d\mathcal{T} + n(t) \tag{2.24}$$

This passed through an analogue-to-digital converter, whose output sequence ym, m = 0......2N −1 which is y(t) sampled at rate 1/Td. The discrete-time baseband equivalent received signal is given by

$$y_m = H\left(\sum_{i=1}^{B} F_i V_i S_i\right) + n \tag{2.25}$$

This explains a traditional linear model of the received signal, which may be used to recover QAM symbols using signal processing techniques like as equalizers and FFT. Frequency-domain FFT-based receiver processing is an option. Single-tap per-subcarrier frequency domain equalizers, similar to OFDM, can be used to balance the combined influence of the radio channel and the subband filter.

If the channel impulse response is ideally Delta-Dirac function δ(t), time domain preprocessing is not used and CFO and timing offset are not taken into account, the estimated from m-th symbol y_m can be written as:

$$\hat{s}_i = \sum_{i=0}^{B} y_{i,m} e^{\frac{j2\pi k}{N}} \qquad k = 0,1 \ldots\ldots\ldots 2N-1 \tag{2.26}$$

UFMC, unlike OFDM, divides sub-carriers into sub-bands and applies filtering to each one independently, reducing out-of-band emission while maintaining the benefits of OFDM.

CHAPTER THREE

3. METHODOLOGY

3.1. Introduction

OFDM, as a multi-carrier modulation technique, has been widely adopted by 4G communication systems, such as LTE and Wi-Fi®. It has a number of advantages, including channel delay resistance, single-tap frequency domain equalization, and ease of implementation. The drawbacks, such as the loss of spectral efficiency due to increased side lobes and the rigorous synchronization requirements, are frequently overlooked.

New modulation techniques are being studied for 5G communication networks to alleviate some of these concerns.

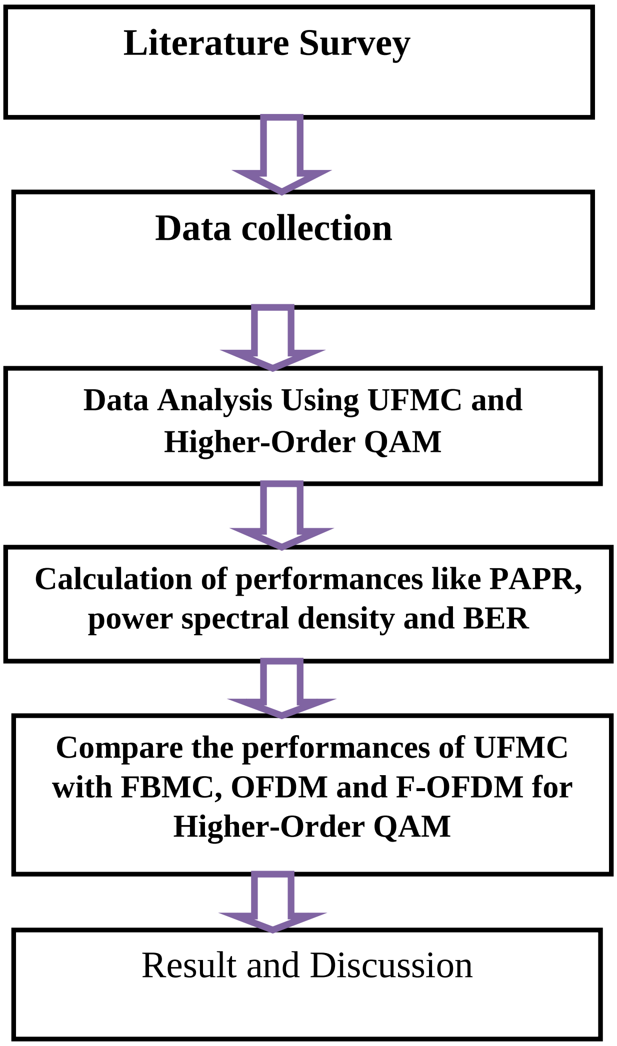
An LTE system with a 20 MHz channel bandwidth, for example, uses 100 resource blocks with 12 subcarriers apiece and a 15 kHz individual subcarrier spacing. This uses just 18 MHz of the authorized spectrum, resulting in a 10% reduction in capacity. Furthermore, the cyclic prefix of 144 or 160 samples per OFDM symbol results in a further 7% efficiency loss, for a total of 17% spectral efficiency loss. Applications require faster data speeds, lower latency, and more efficient spectrum usage, as outlined by the ITU criteria for 5G systems. This example compares UFMC to OFDM in a generic framework and concentrates on the new modulation technology known as Universal Filtered Multi-Carrier (UFMC).

3.2 Materials

In this work we used MATLAB software. We used matlab to analyze performance of the system at different modulation

3.3 Methods

To do this thesis and attain the general and specific objectives, the following procedural methods were followed.



3.4 UFMC Transmission

Filtered OFDM and FBMC (Filter Bank Multi-carrier) modulations are considered as a generalization of UFMC. Individual subcarriers and groups of subcarriers (sub-bands) are filtered in filtered OFDM, while the entire band is filtered in UFMC. This subcarrier grouping allows the filter length to be reduced (when compared with FBMC).

In addition, as compared to FBMC, UFMC can still use QAM since it retains the complex orthogonality that works with existing MIMO schemes. Sub-bands are created from the whole band of subcarriers (N).

Each sub band has a set number of subcarriers, and not all sub bands are required for each transmission. For each sub band, an N-pt IFFT is computed, with zeros inserted for the unallocated carriers. The responses from the multiple sub-bands are totaled after each sub-band is filtered by a filter of length L. The filtering is done to reduce spectral emissions that are outside of the band. Different filters can be applied to each sub band, however in this example; the same filter is applied to each sub band. To filter the IFFT output per sub band, a Chebyshev window with parameterized side-lobe attenuation is used. [39].

The transmit-end processing is shown in the following diagram.

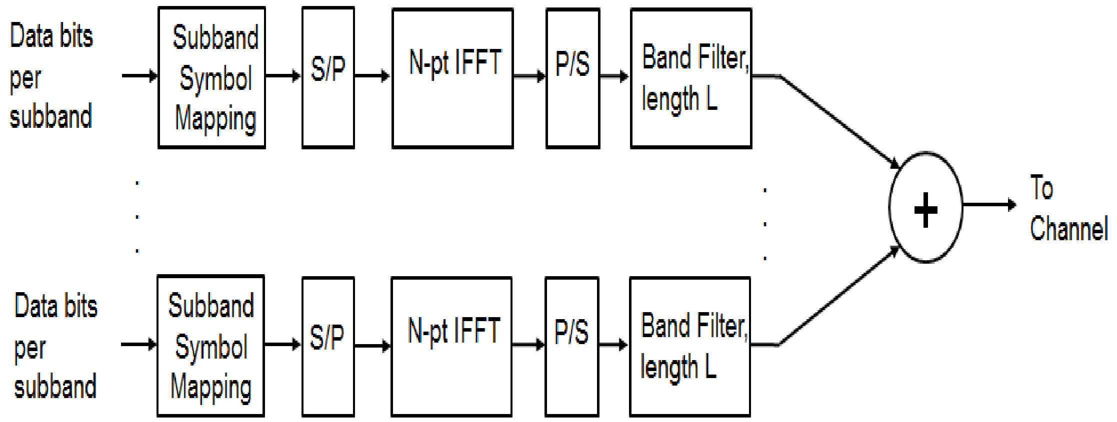


Figure 3.1: Transmitter Section of MIMO block

When the spectral densities of the OFDM and UFMC schemes are plotted side-by-side, the UFMC scheme has lower side-lobes. This enables for more efficient use of the allocated spectrum, resulting in improved spectral efficiency. In addition, UFMC has a somewhat higher PAPR.

3.4.1 UFMC Receiver with No Channel

The following example illustrates the fundamental UFMC receive processing, which, like OFDM, is based on FFT. For the FFT process, sub band filtering expands the reception time window to the next power-of-two length. A subcarrier main lobe corresponds to each alternate frequency value. In most cases, per-subcarrier equalization is employed to balance the channels and sub band filtering combined effects. Because no channel effects are considered, just the sub band filter is equalized in this example. To obtain the necessary SNR, noise is injected to the received signal.

The receive-end processing is shown in the following diagram.

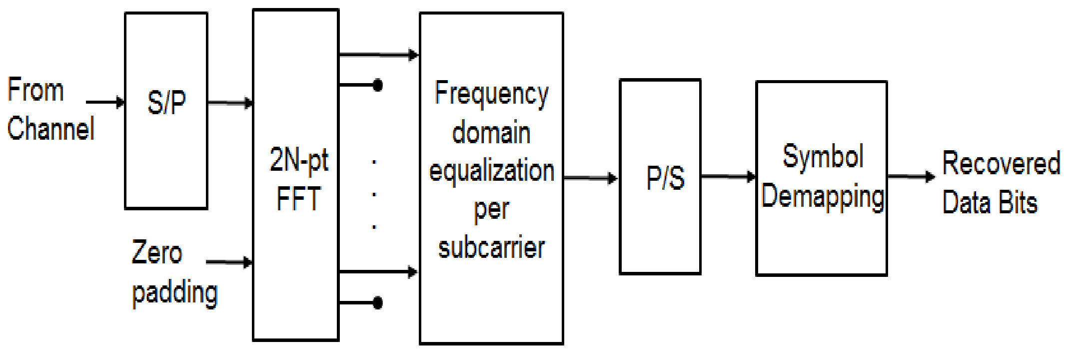


Figure 3.2: Receiver Section of UFMC MIMO block

At both transmit and receive ends of a communication system, the example shows the basic properties of the UFMC modulation scheme. For the number of sub-bands, number of subcarriers per sub-band, filter length, side-lobe attenuation, and SNR, experiment with different system parameter values.

3.5 Filter Bank Multi-Carrier Modulation

In a multicarrier system, FBMC filters each subcarrier modulated signal. The prototype filter is utilized for zero frequency carriers and serves as the foundation for all subsequent subcarrier filters. The overlapping factor, K, is the number of multicarrier symbols that overlap in the time domain and is used to describe the filters. The prototype filter order can be chosen as $2*K-1$ where K = 2, 3, or 4 and is selected as per the PHYDYAS project [32].

Frequency spreading is used in the present FBMC implementation.

It employs a N*K length IFFT with overlapping symbols and a delay of N/2, where N is the number of subcarriers. This design choice makes analysing FBMC and comparing it to other modulation schemes simple.

Offset quadrature amplitude modulation (OQAM) processing is used to reach full capacity. Because the imaginary part of a complex data symbol is delayed by half the symbol duration, the real and imaginary parts of the symbol are not transmitted simultaneously.

The transmit-end processing is shown in the following diagram.

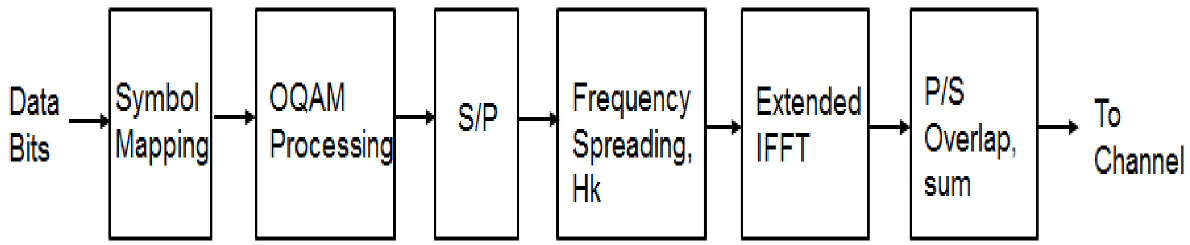


Figure 3.3: Transmitter Section of FBMC MIMO block

The power spectral density of the FBMC transmit signal is plotted to highlight the low out-of-band leakage.

3.5.1 FBMC Receiver with No Channel

In the absence of a channel, the example creates a rudimentary FBMC demodulator and measures the BER for the selected configuration. To form the received data symbols, the processing includes matched filtering followed by OQAM separation. These are de-mapped to bits, and the bit error rate as a result is calculated. Linear multi-tap equalizers can be used to lessen the effects of frequency-selective fading in the presence of a channel.

The receive-end processing is shown in the following diagram.

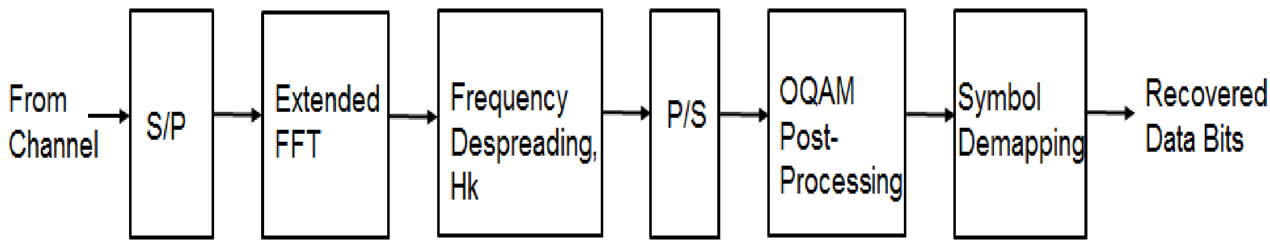


Figure 3.4: Receiver Section of FBMC MIMO block

3.6 OFDM MIMO system

The main advantages of the OFDM are –

- ❖ **Immunity to selective fading:** The key advantages of OFDM is its greater resistance to frequency selective fading, than the single carrier systems as it divides entire channel into many narrowband signals individually affected by the flat fading sub-channels.

- **Resilience to interference:** Channel interference can be limited by bandwidth and do not therefore affect all sub channels. This ensures that not all knowledge has been lost.
- **Spectrum efficiency:** With close-spaced overlapping of the subcarriers, an important benefit of the OFDM is that, the available spectrum is efficient.
- **Resilient to ISI:** Another advantage of OFDM is its high resilience to inter-symbol interference and inter-frame interference. This is due to the low data rate of each sub channel.

The transmitter and receiver of the OFDM MIMO systems have 2 antennas at both the ends. At the transmitter, the data bits are streams are mapped and then sent to space time encoder. Each symbol is passed through the serial to parallel (S/P) converter and hence we receive the parallel data. Then, the IFFT is performed, which converts frequency domain to time samples employing OFDM modulation in each sub-carrier. Time domain symbols are then passed to the parallel to serial (P/S) converter and then the cyclic prefix (CP) is added in order to eliminate ISI inter -symbol interference and ICI (inter-carrier interference). At the end, the amplified modulated signals are transmitted.

The transmitter block diagram is shown in the Fig. 3.5

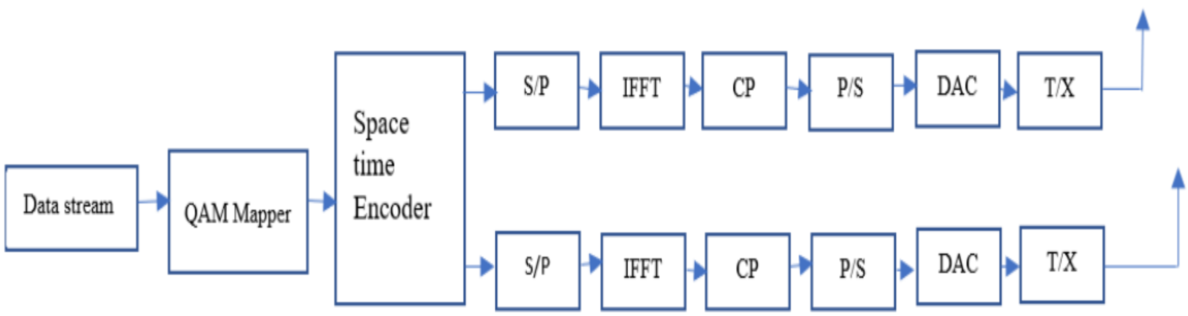


Figure 3.5: Transmitter Section of OFDM MIMO block

At the receiver Fig 3.6, reverse operation is performed. The received signal is converted to the digital form and then the cyclic prefix is removed. The time domain signal is converted back to the frequency domain using FFT block and then the data is decoded, and the data bits are obtained. [40]

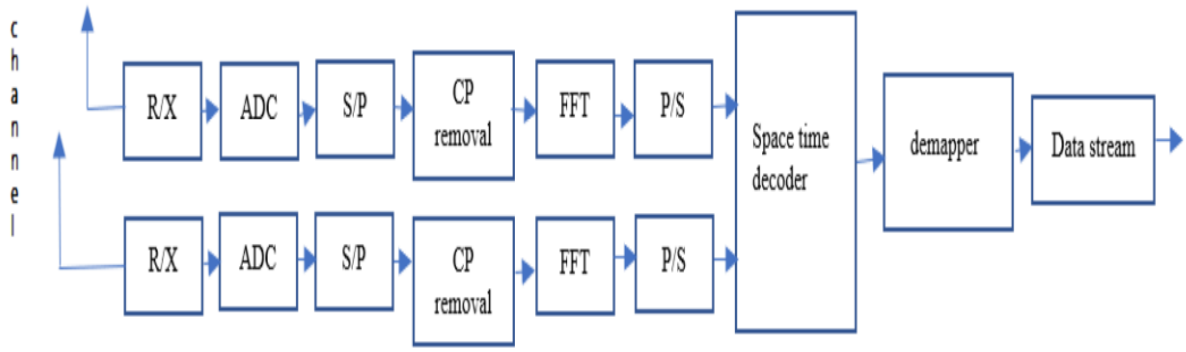


Figure 3.6: Receiver Section of OFDM MIMO block

3.6.1 OFDM Modulation with Corresponding Parameters

For comparison, we look at an existing OFDM modulation approach that uses the entire occupied band but doesn't need a cyclic prefix.

When comparing the spectral densities of the OFDM and FBMC systems, the FBMC scheme exhibits lower side lobes. This enables for more efficient use of the allocated spectrum, resulting in improved spectral efficiency.

Performance Analysis Parameter

We have used only two performance parameters in this work. These are given as PAPR and BER.

Peak to average power ratio

Fundamental drawback of multicarrier modulation systems is that the input data stream is fragmented into numerous sub streams, resulting in the largest peak to average power ratio. Sub carriers are the names for these sub streams. The subcarriers are modulated (independently) at distinct carrier frequencies, resulting in a high PAPR that may be summed together for transmission purposes. When N signals are joined in the same phase, the signal's peak power is created [33]. When N times the average power of a signal is created, the signal's peak power is produced. As a result, the PAPR value in multicarrier signals is extremely high.

The Peak to Average Power Ratio is calculated by multiplying the peak power by the average power.

$$\boldsymbol{PAPR} = \frac{\boldsymbol{max}\{|\boldsymbol{X}(\boldsymbol{t})|\}^{2}}{\boldsymbol{E}\{|\boldsymbol{X}(\boldsymbol{t})|\}^{2}}$$

Bit error

The rate at which mistakes occur in a transmission system is known as the BER. In its most basic form,

$$BER = \frac{Number\ of\ Error\ bits}{Number\ of\ Sent\ Bits}$$

$$BER = \int_{0}^{\infty} p_r\left({}^{E}/_{r}\right) p(r) dr$$

Where, $P_b(E/r)$ = the conditional probability and p(r)= the probability density function of the SNR.

Parameters used in this Study for Simulation of Multicarrier Modulation Techniques

Table 3.1: Parameters used in this study for simulation of 5G waveforms.

Parameters common to all modulation technique	Number of FFT points = 1024 Bit-per-sub-carrier = 2, 4, 6 and 8 Number of resource block = 50
Parameters used for FBMC	Overlapping symbols = 2, 3, 4 k = 4 Simulation length in symbols = 100 Filter length = 43 SNR in dB = 18dB
Parameters used for F-OFDM	Number of sub-carriers per resource block = 20 Cyclic prefix length = 72 Tone offset = 2.5 Filter length (is an odd number) = 513 Total number of guards on both sides = 212 SNR in dB = 18dB
Parameters used for UFMC	Sub band size = 20 Number of sub bands = 10 Number of sub band offset = 156 Side lobe attenuation = 40dB Filter length = 43 SNR in dB = 18dB

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Introduction

There is a comparison of the candidate multicarrier modulation schemes. The settings used in this simulation might change depending on the comparison measurements. Under a multipath channel, the following results were simulated and produced, comparing the performance of OFDM, FBMC, and UFMC for QAM schemes. QAM was chosen since it is frequently used for data transmission because it has a higher spectral efficiency than other modulations.

We simply assume a single transmitting antenna at the base station and a single user at the single receiving antenna to emphasize link level performance. Also assumed is flawless channel estimation, which aids in highlighting the differences in performance between modulation schemes. In addition, guard intervals are used in CP-OFDM and UFMC to prevent ISI.

16-QAM

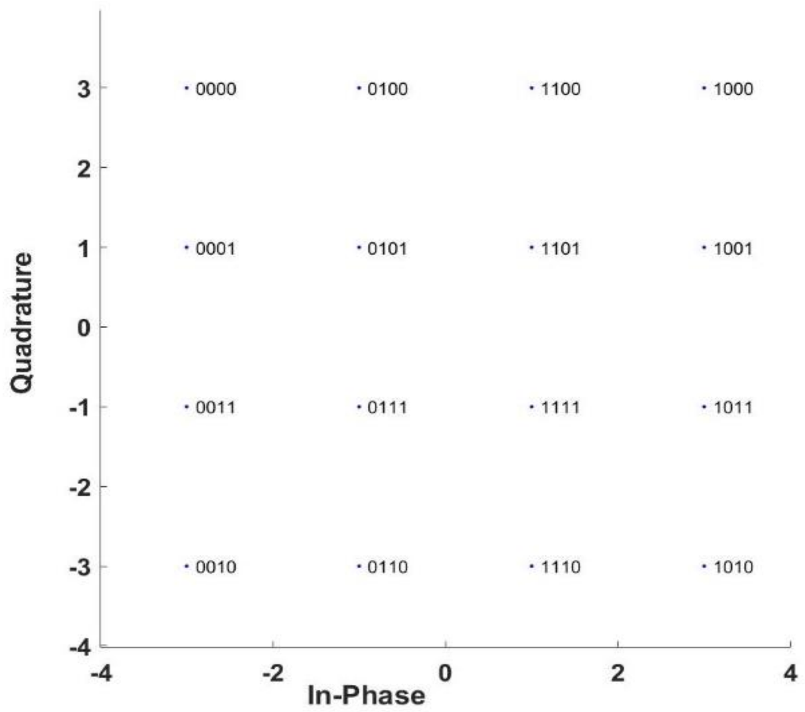


Figure 4.1: 16 QAM bits

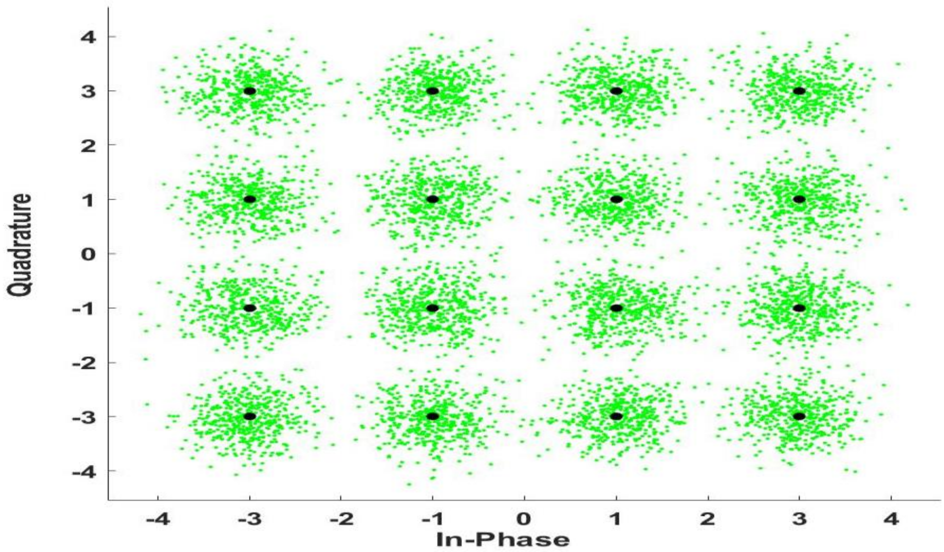


Figure 4.2: 16 QAM scattered

The noise causes symbols to "scatter" about the ideal constellation points, as seen in the diagram above. Because Gaussian noise samples are separate, the noise impacts each sent symbol independently during the detection process of a channel with AWGN.

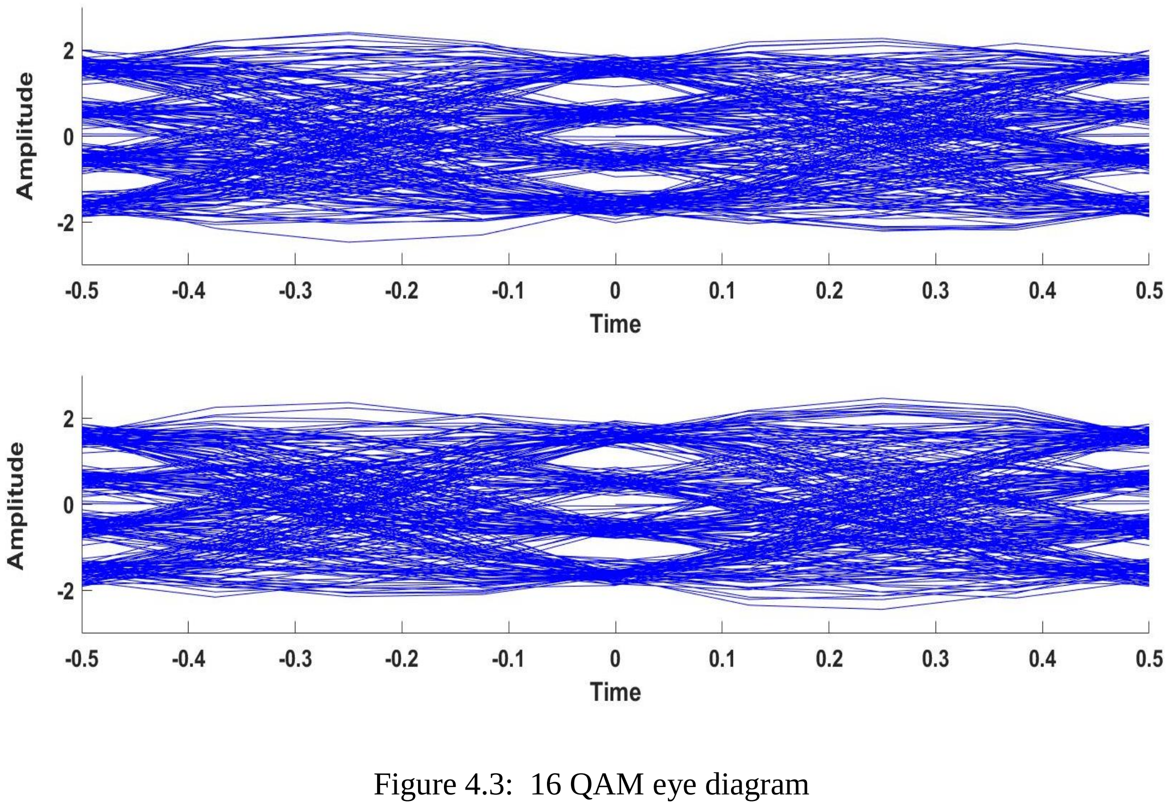


Figure 4.3: 16 QAM eye diagram

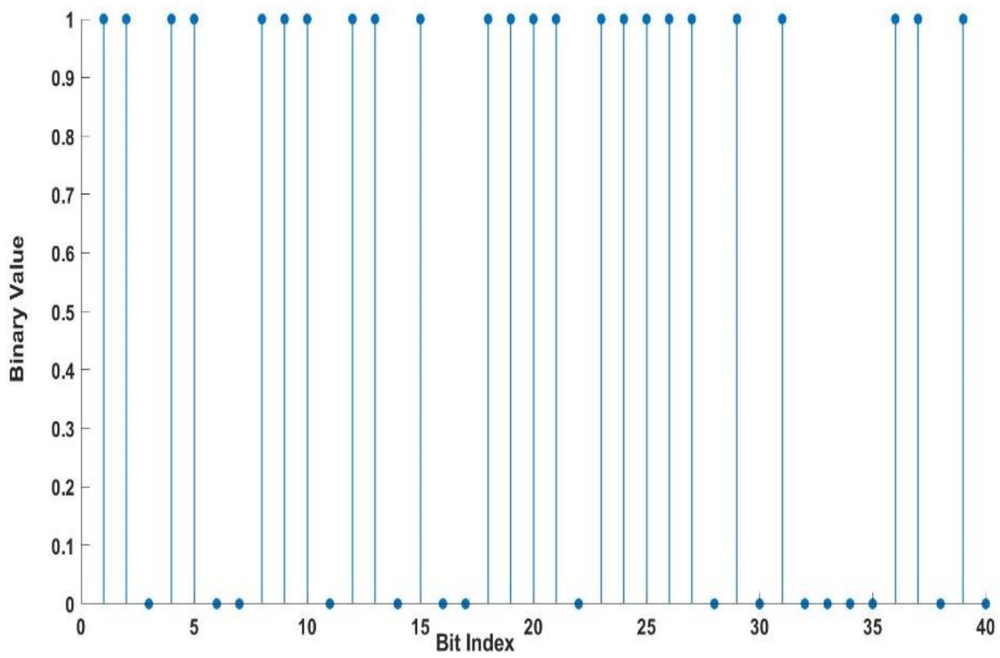


Figure 4.4: 16 QAM binary data

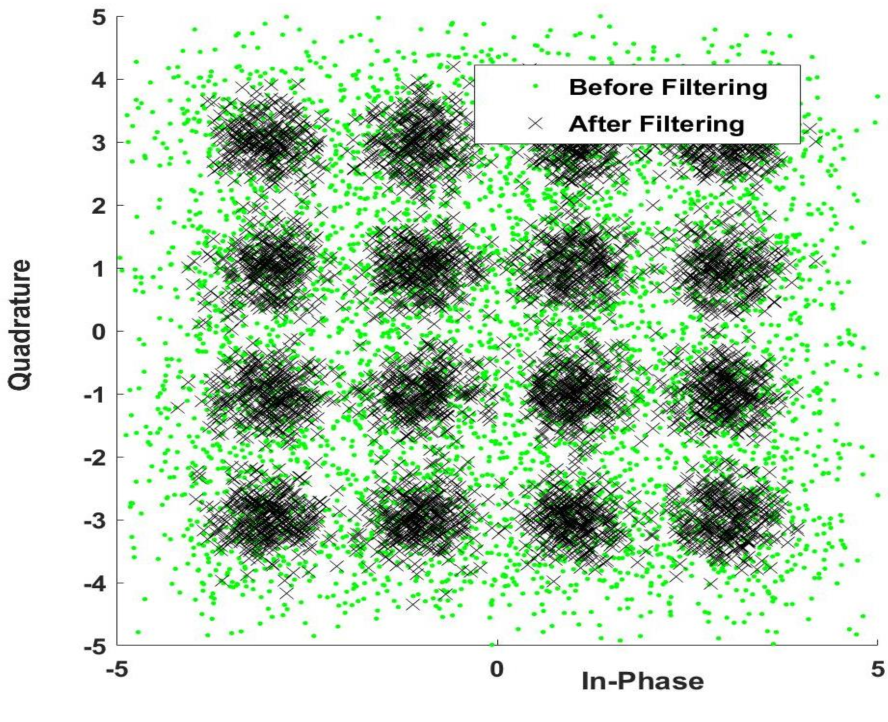


Figure 4.5: 16 QAM before filtering and after filtering

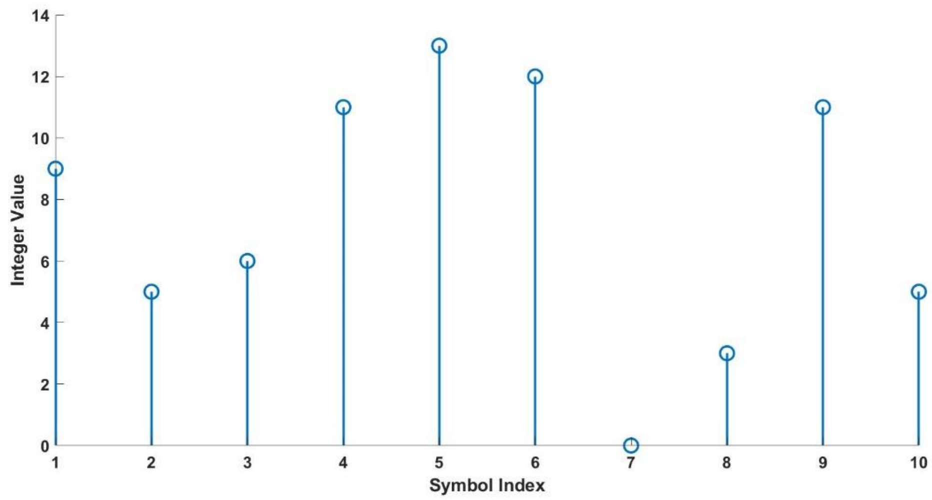


Figure 4.6: 16 QAM symbol index

64-QAM

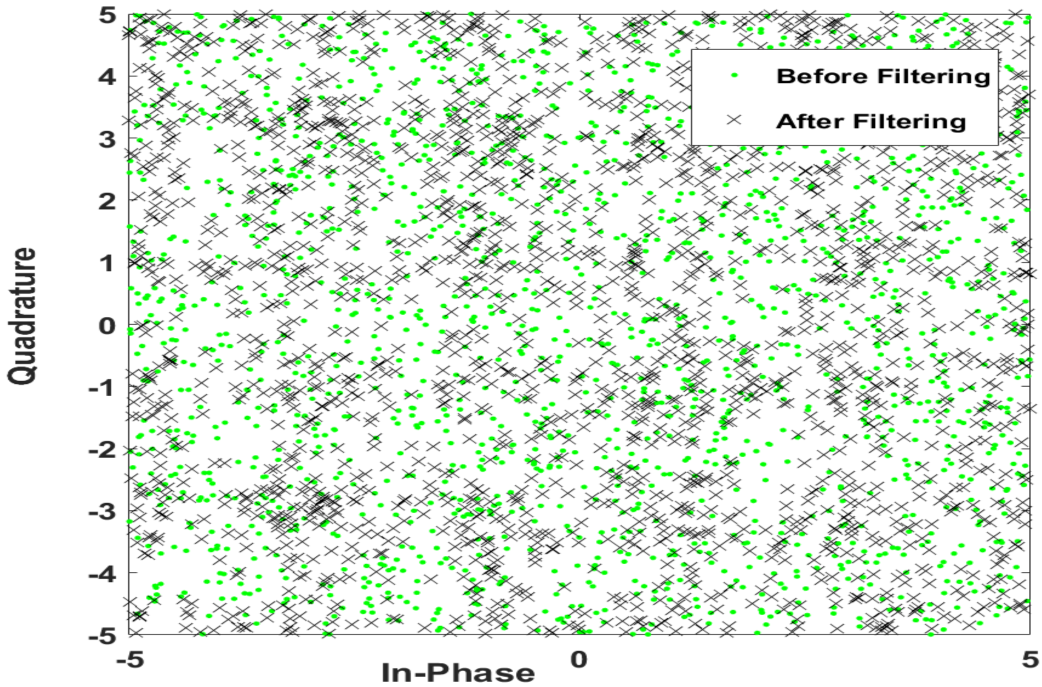


Figure 4.7: 64 QAM before filtering and after filtering

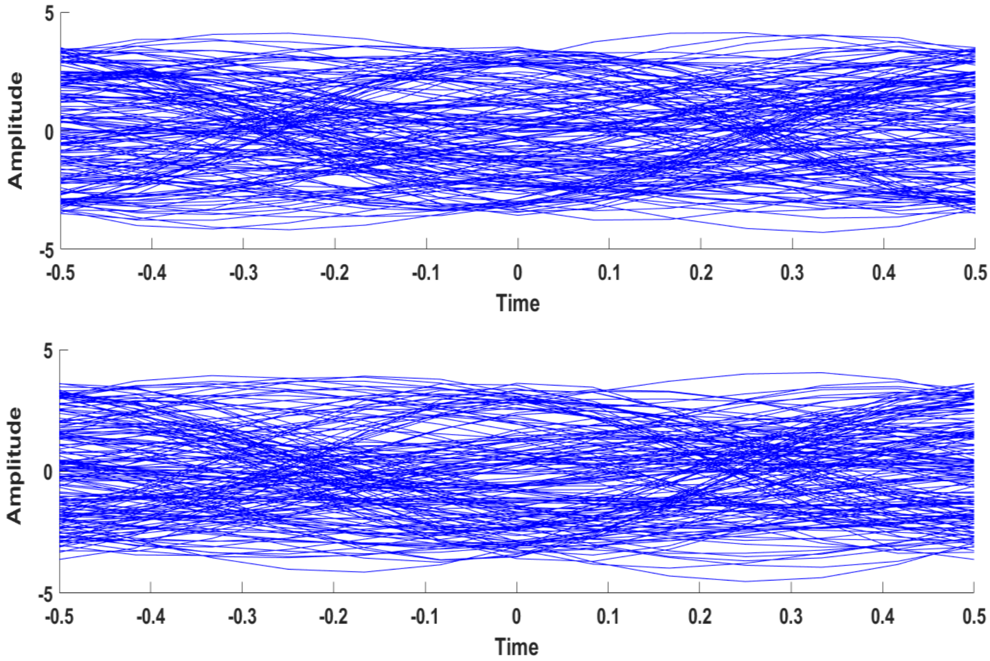


Figure 4.8: 64 QAM eye diagram

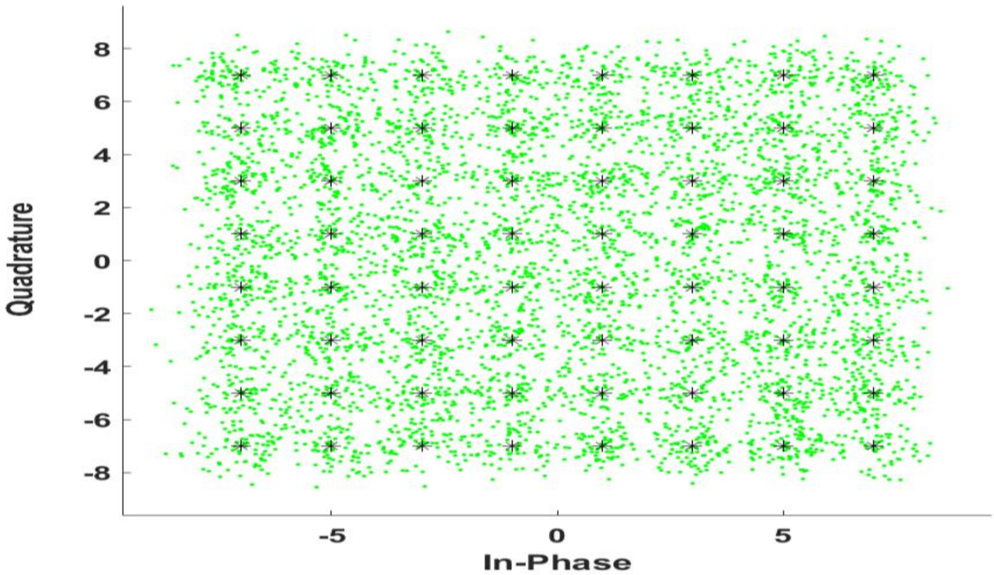


Figure 4.9: 64 QAM scattered

The noise causes symbols to "scatter" about the ideal constellation points, as seen in Figure 4.9. Because Gaussian noise samples are separate, the noise impacts each sent symbol independently during the detection process of a channel with AWGN.

256-QAM

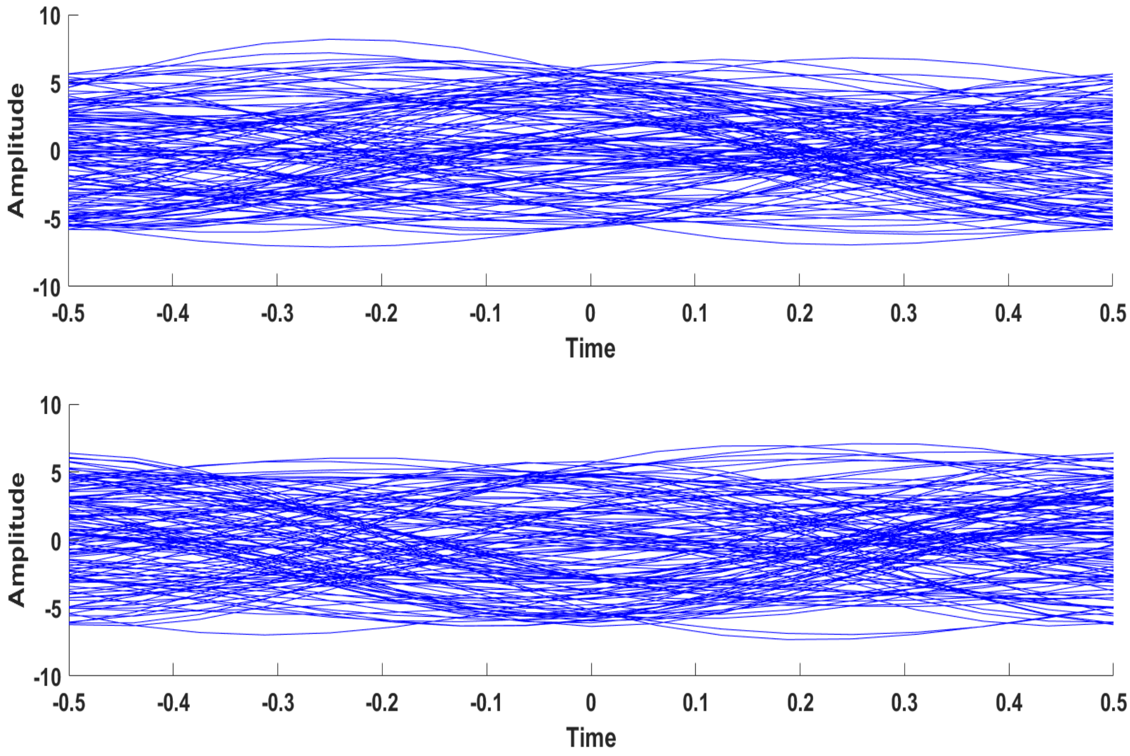


Figure 4.10: 256 QAM eye diagram

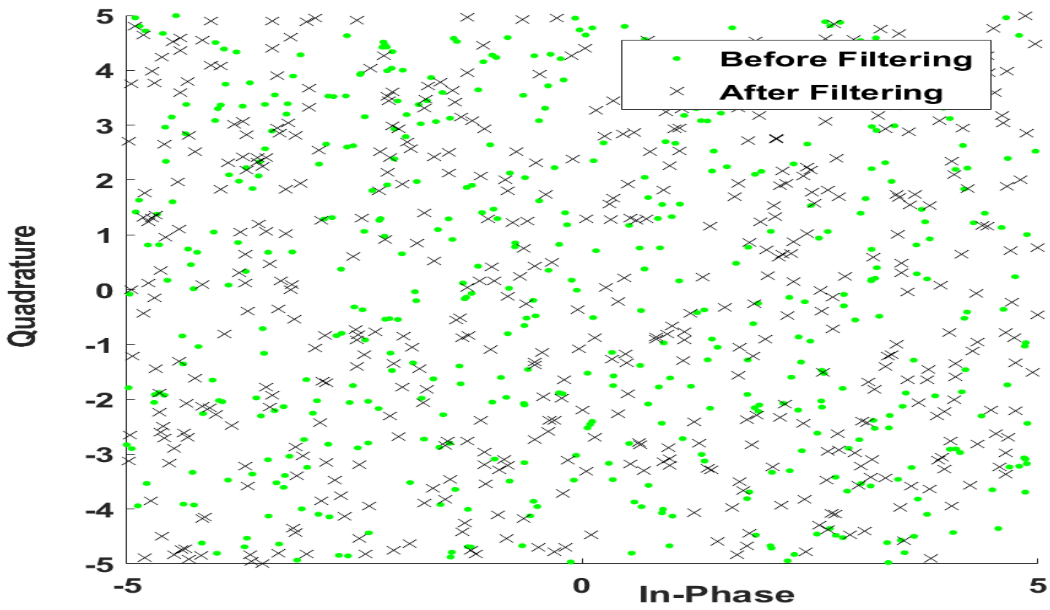


Figure 4.11: 256 QAM before filtering and after filtering

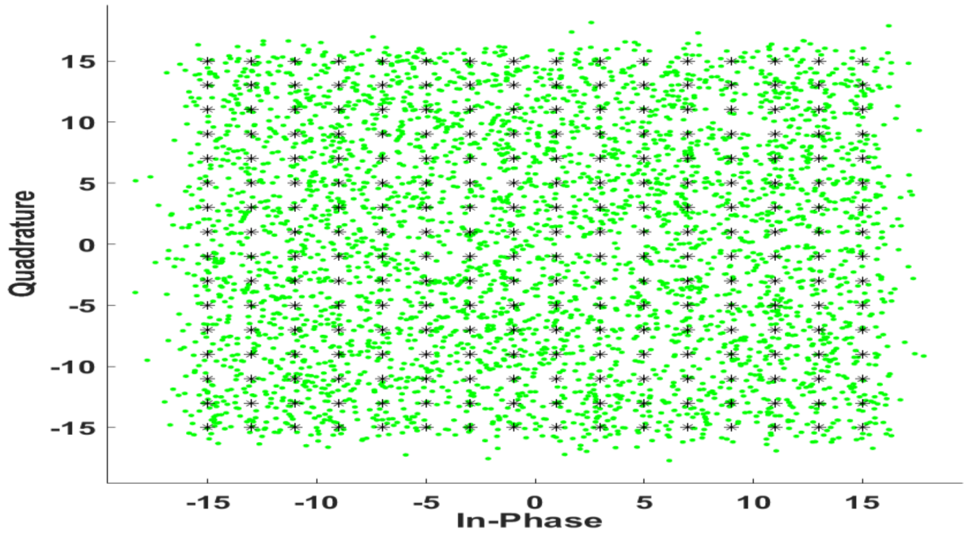


Figure 4.12: 256 QAM scattered

The noise causes symbols to "scatter" about the ideal constellation points, as may be seen in the diagram above. Because Gaussian noise samples are separate, noise impacts each transmitted symbol independently during the detection process of a channel with AWGN.

1024-QAM

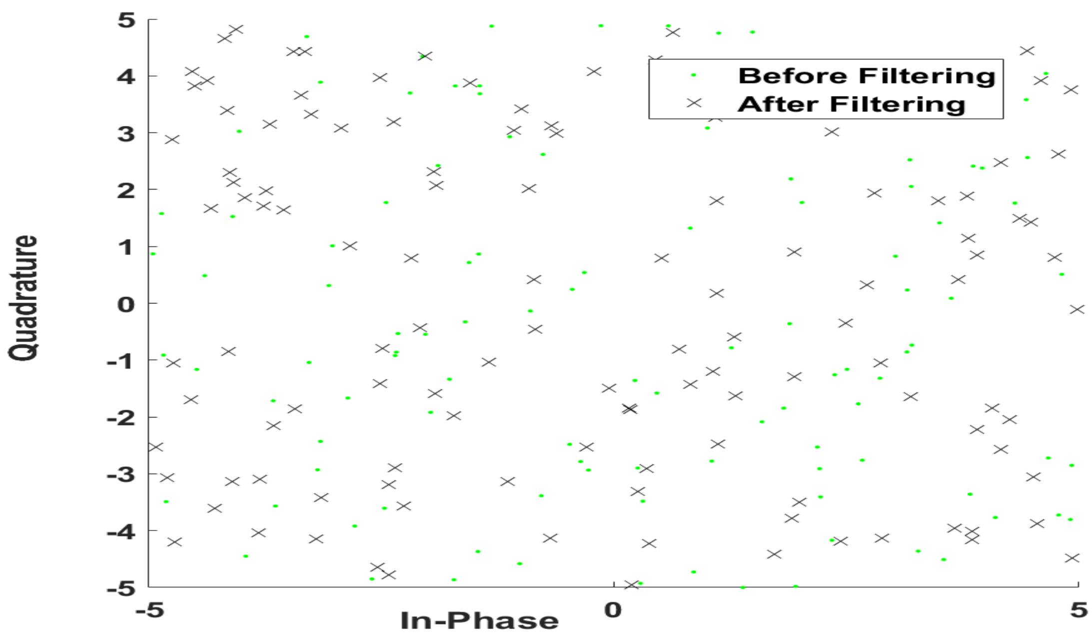


Figure 4.13: 1024 QAM before filtering and after filtering

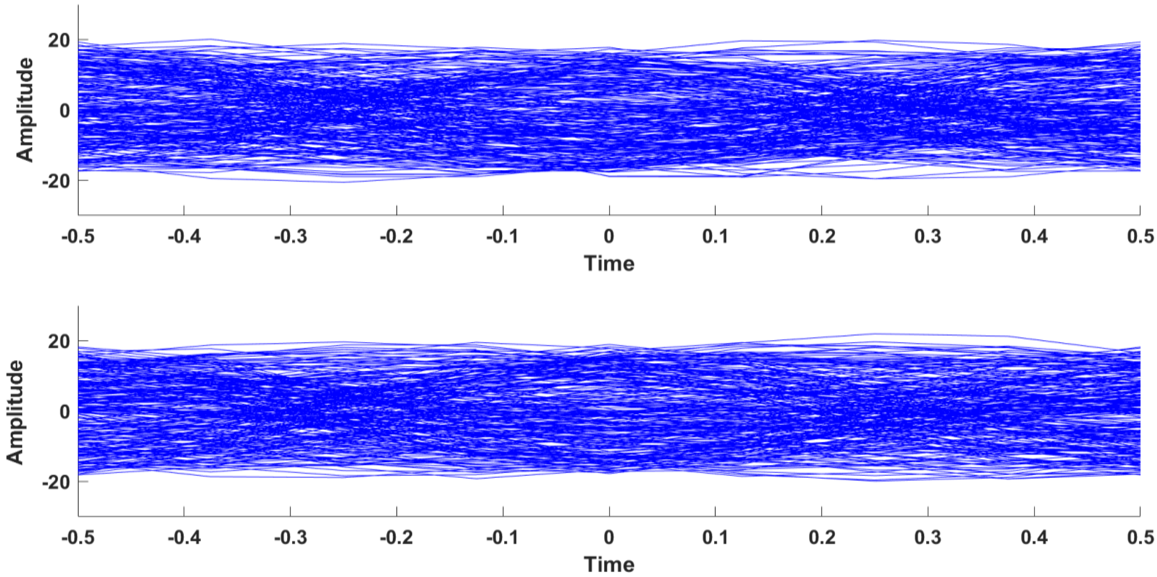


Figure 4.14: 1024 QAM eye diagram

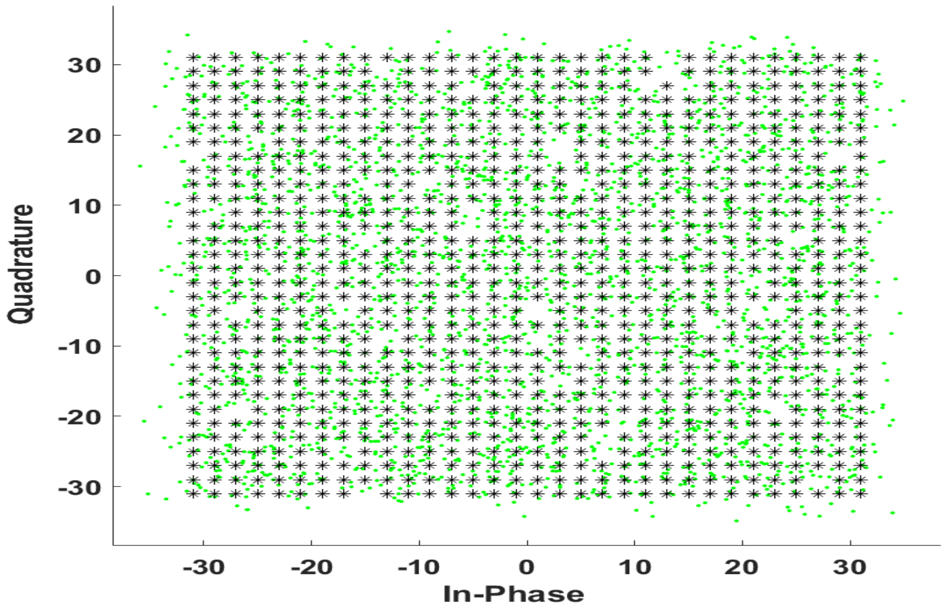


Figure 4.15: 1024 QAM scattered

The noise causes symbols to "scatter" about the ideal constellation points, as shown in the above figure. Because Gaussian noise samples are separate, the noise impacts each transmitted symbol independently in the detection process of a channel with AWGN.

Performance evaluation of M-QAM on various noisy conditions

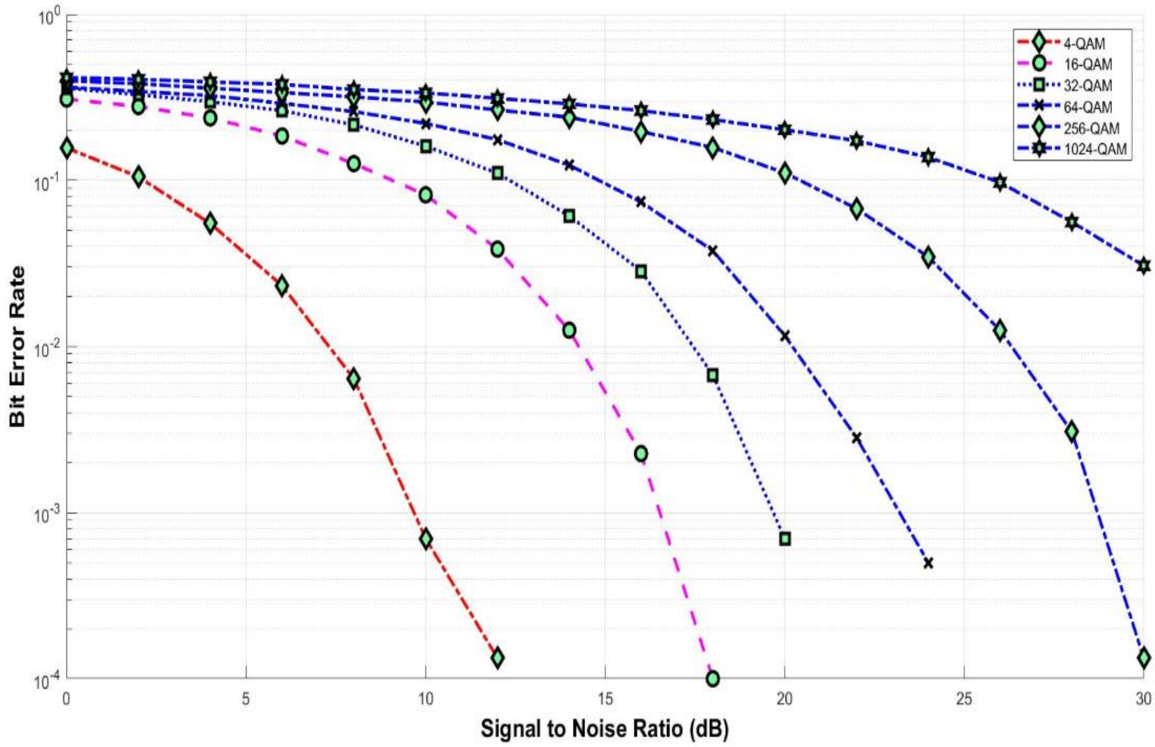


Figure 4.16: SNR of M-QAM for various over sampling factor

The SNR is determined by the QAM order and the sampling factor. As the order of QAM grows, so does the SNR. By using higher order QAM in a communication system, more bits may be sent. The optimum outcome for 1024QAM for oversampling factor is shown in the simulation results. Figure 4.16: The performance of BER for specific operations and fading circumstances, such as binary coding, Gray coding, Pulse shaping using Raised cosine filter, and Error correction using convolution code, is assessed as the order of the QAM grows.

The BER ratio is the number of mistakes divided by the total number of bits delivered. As the BER means improve, the number of mistakes rises, as illustrated in the M-QAM simulation result.

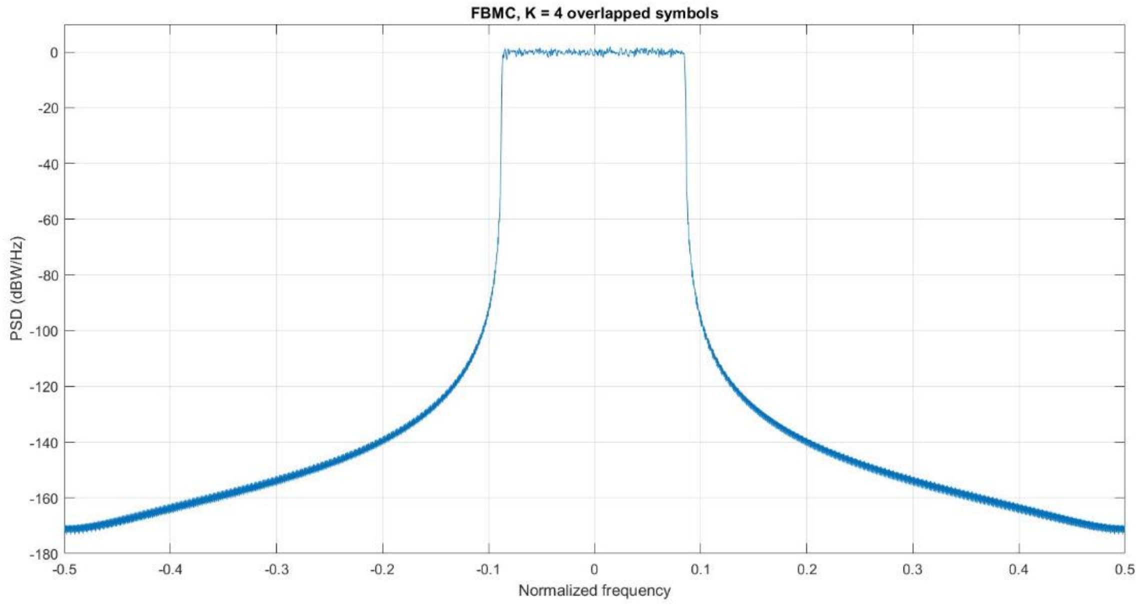


Figure 4.17: Frequency response of FBMC

The power spectral density of the FBMC transmit signal is tailored for reduced out of band leakage. The FBMC has fewer side lobes than the FBMC. As a result, the authorized spectrum may be used more efficiently, resulting in a greater spectral amount. As a result, in terms of spectrum performance, the FBMC system outperforms OFDM MIMO. Figure 4.17 shows the PSD plot of the FBMC MIMO.

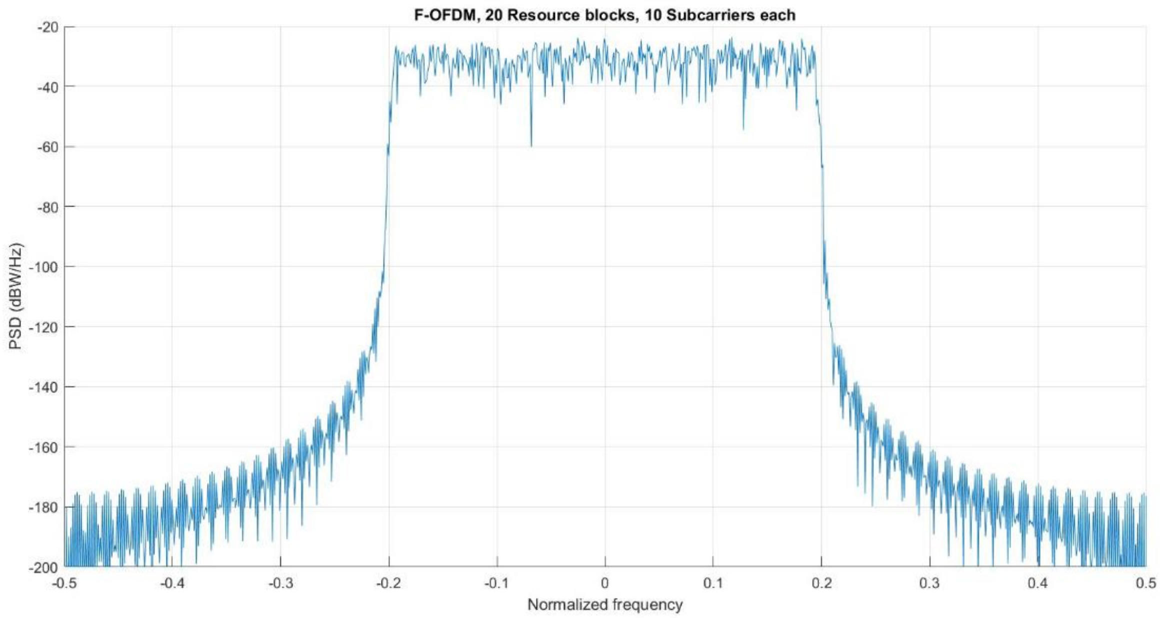


Figure 4.18: Frequency response of F-OFDM

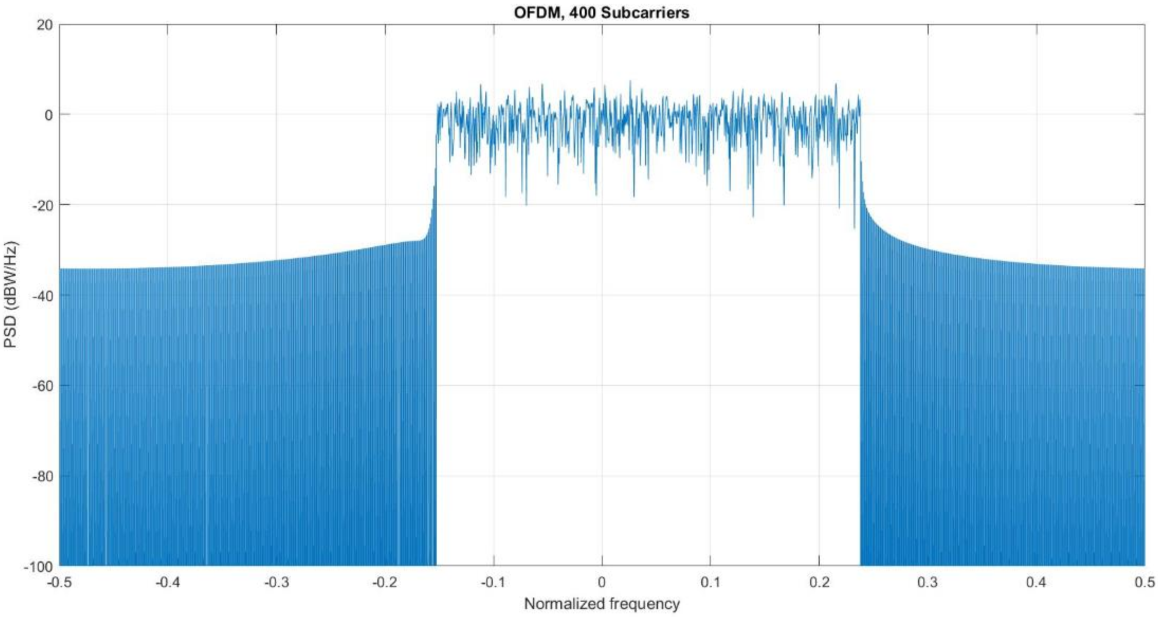


Figure 4.19: Frequency response of OFDM

The power spectral density of the OFDM mimo system is observed as shown in Fig 4.19

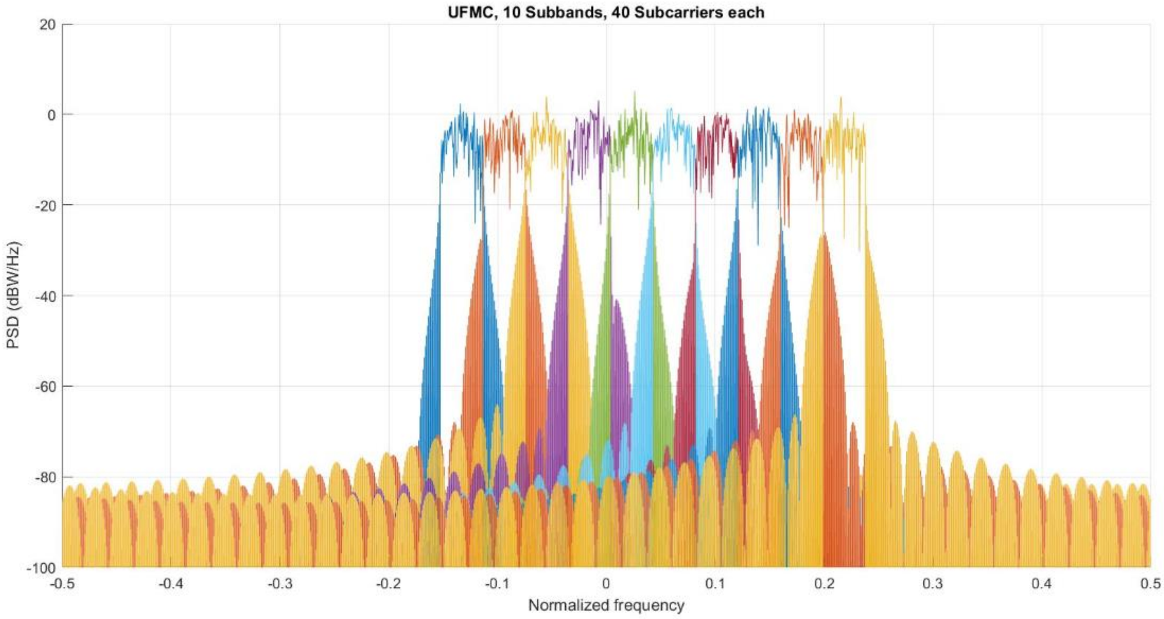


Figure 4.20: Frequency response of UFMC

4.2 ANALYSIS OF FMBC, F-OFDM, OFDM AND UFMC

a) Power Spectral Density (PSD):

Power The intensity of the energy fluctuation as a function may be shown using Spectral Density. It demonstrates where the frequency fluctuations are weaker. The PSD is calculated using the FFT technique. PSD integration generates energy in a specified frequency range.

$$PSD = \frac{Energy[W]}{Frequency[Hz]}$$

b) Peak To Average Power Ratio

The fundamental drawback of multicarrier modulation systems is that the input data stream is fragmented into numerous sub streams, resulting in the largest peak to average power ratio. Sub carriers are the names for these sub streams. The subcarriers are modulated (independently) at distinct carrier frequencies, resulting in a high PAPR that may be summed together for transmission purposes. When N signals are joined in the same phase, the signal's peak power is created. When N times the average power of a signal is created, the signal's peak power is produced. As a result, the PAPR value in multicarrier signals is extremely high. The Peak to Average Power Ratio is calculated by multiplying the peak power by the average power.

$$PAPR = \frac{max\{|X(t)|\}^2}{E\{|X(t)|\}^2}$$

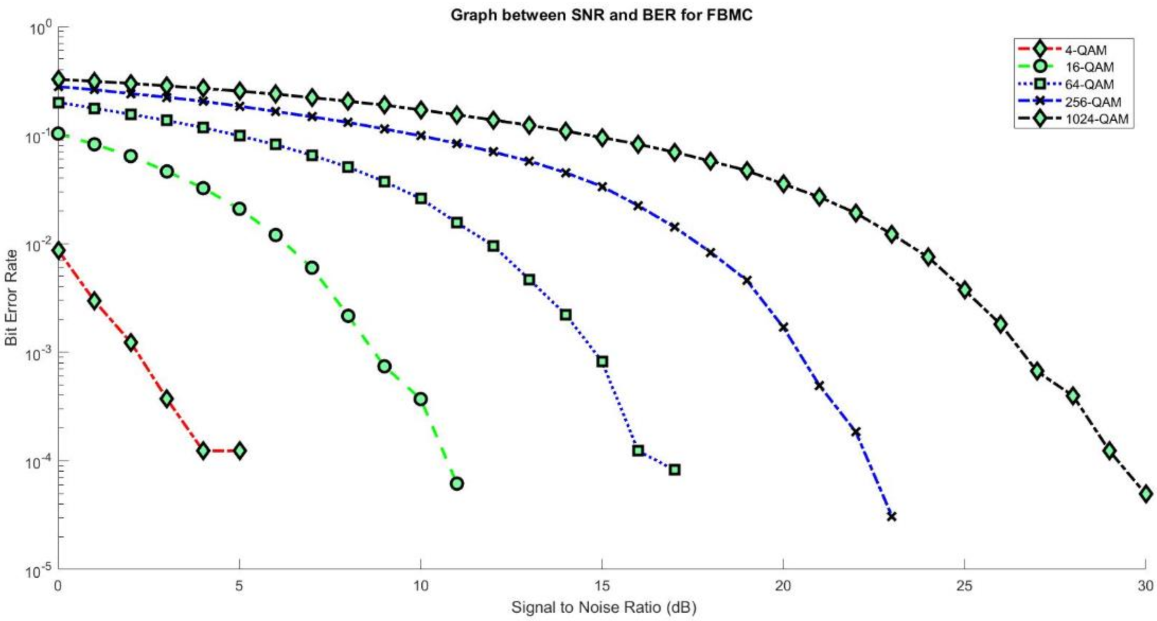


Figure 4.21: BER 512 FBMC

The bit error rate (BER) is the number of mistakes per unit of time. It's a crucial metric for assessing system performance.

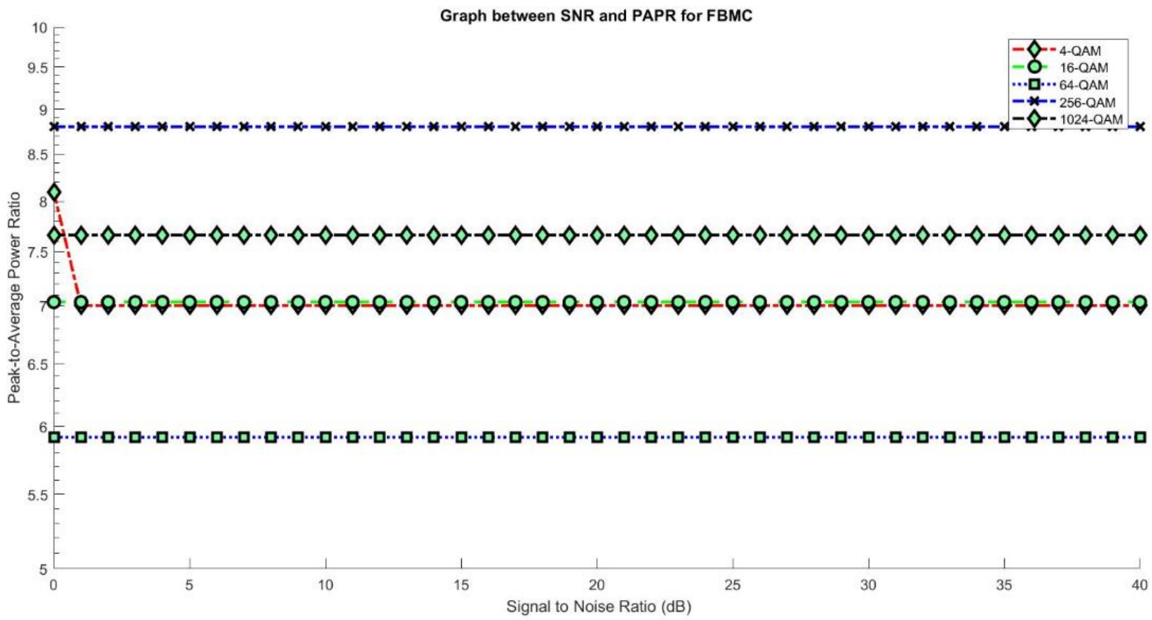


Figure 4.22: PAPR 512 FBMC

The high peak-to-average power ratio (PAPR) of transmitted FBMC-OQAM signals is one of the key issues with FBMC-OQAM systems. Due to the narrow linear range of the high-power amplifier employed in FBMC-OQAM systems, FBMC OQAM signals with high PAPR will be severely clipped and nonlinear distortion will be added, resulting in a significant reduction of bit error rate performance. It is extremely important in signal processing applications. If the PAPR is lower, the system is more efficient.

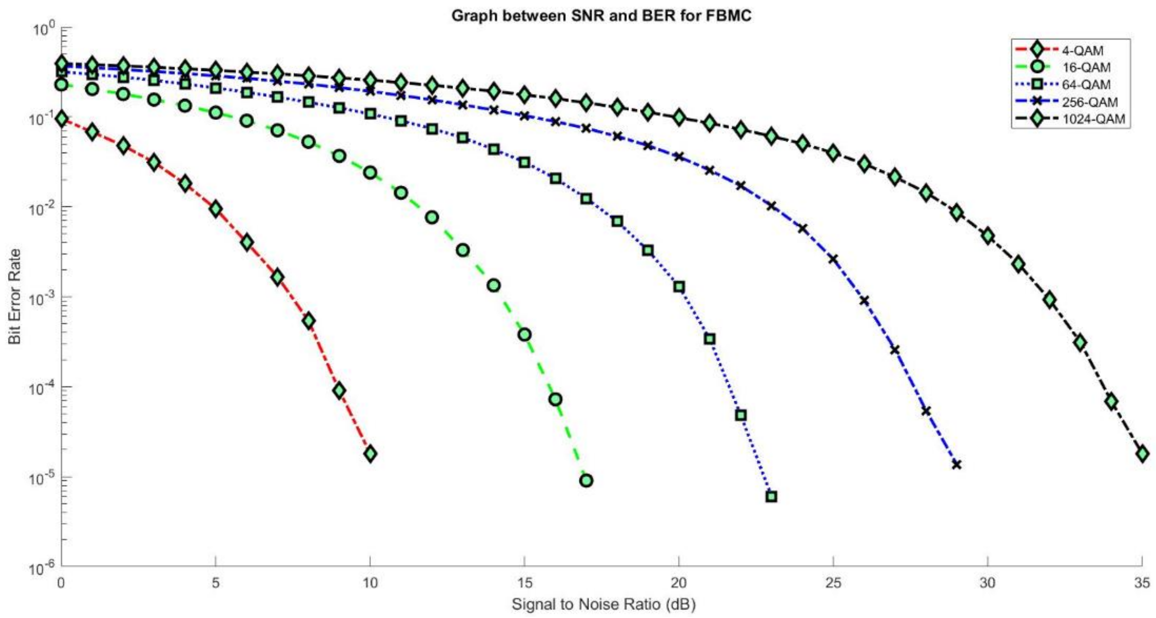


Figure 4.23: BER 1024 FBMC

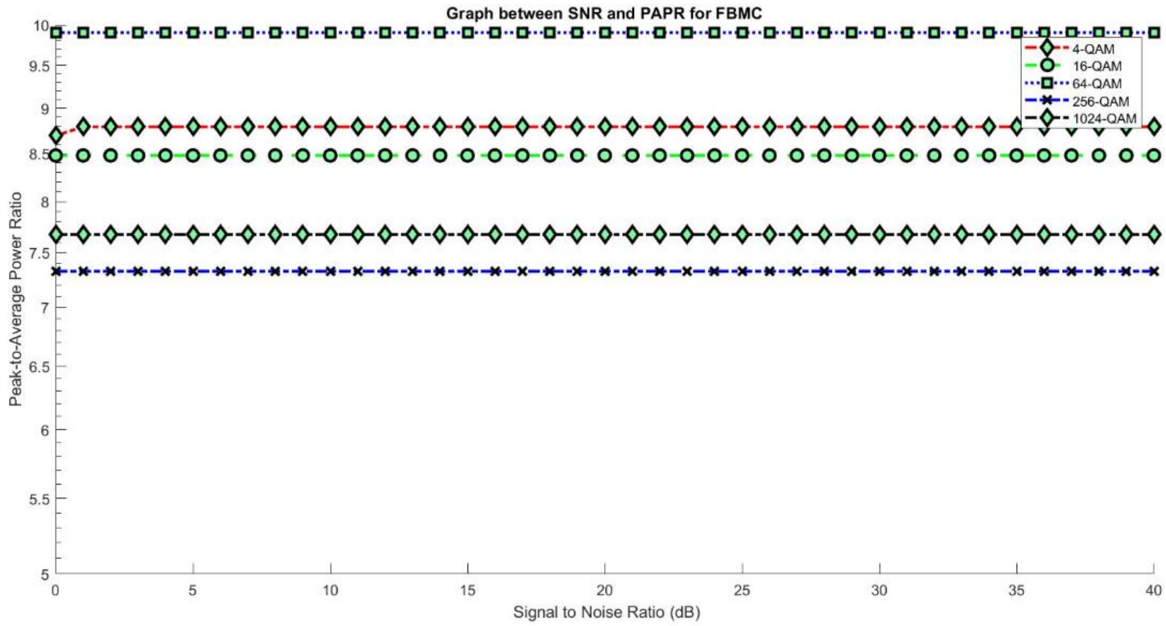


Figure 4.24: PAPR 1024 FBMC

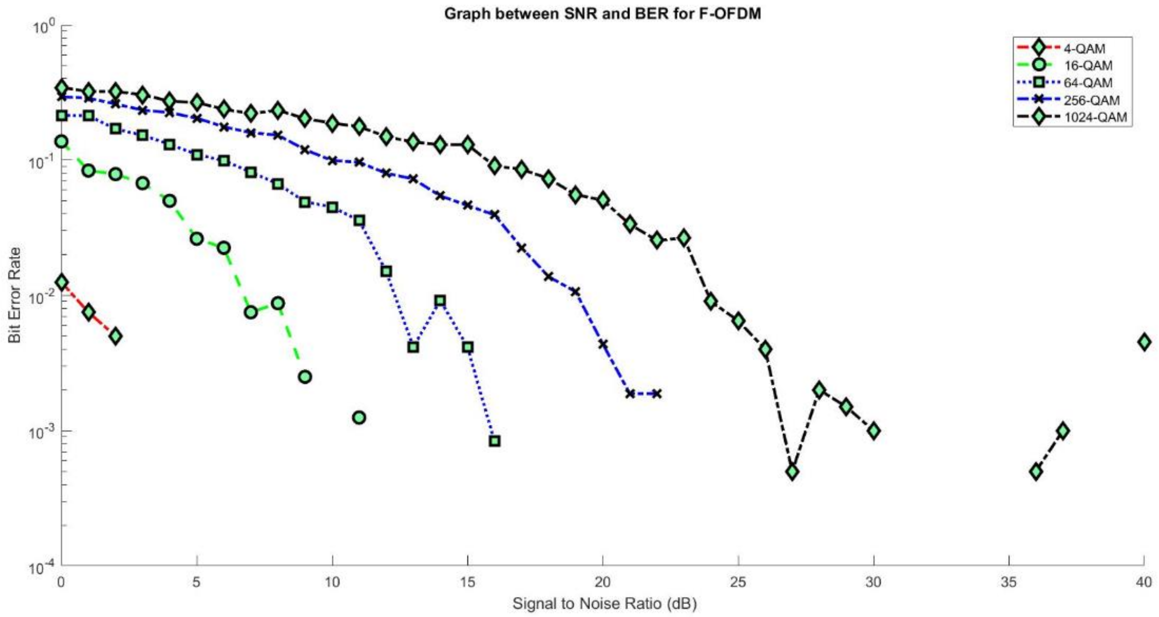


Figure 4.25: BER 512 F-OFDM

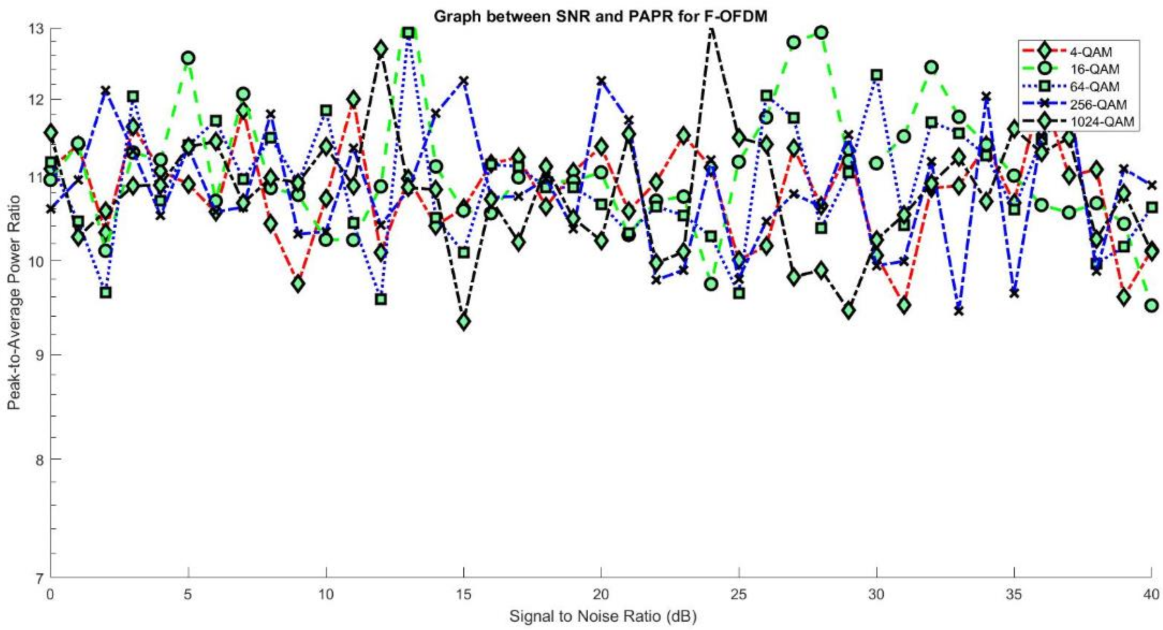


Figure 4.25: PAPR 512 F-OFDM

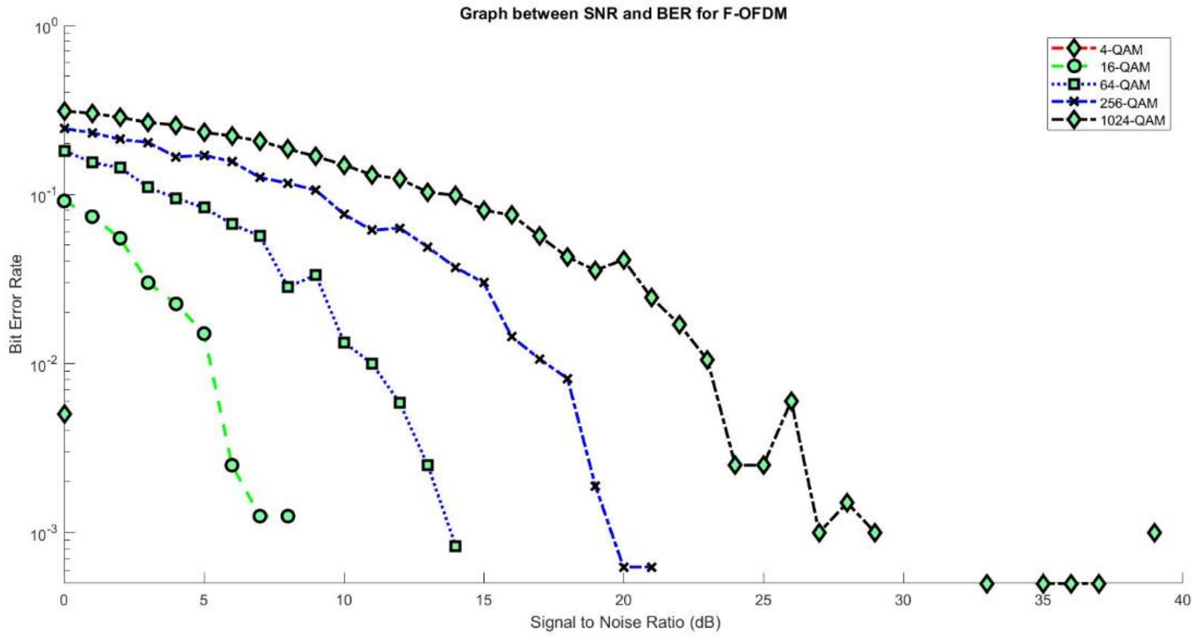


Figure 4.27: BER 1024 F-OFDM

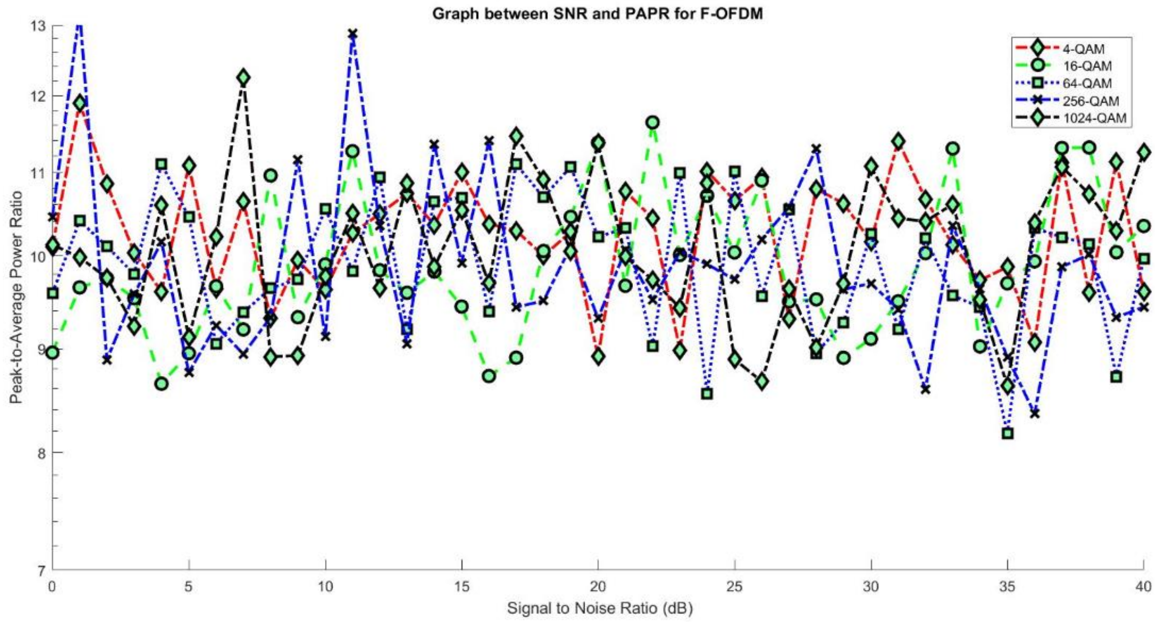


Figure 4.28: PAPR 1024 F-OFDM

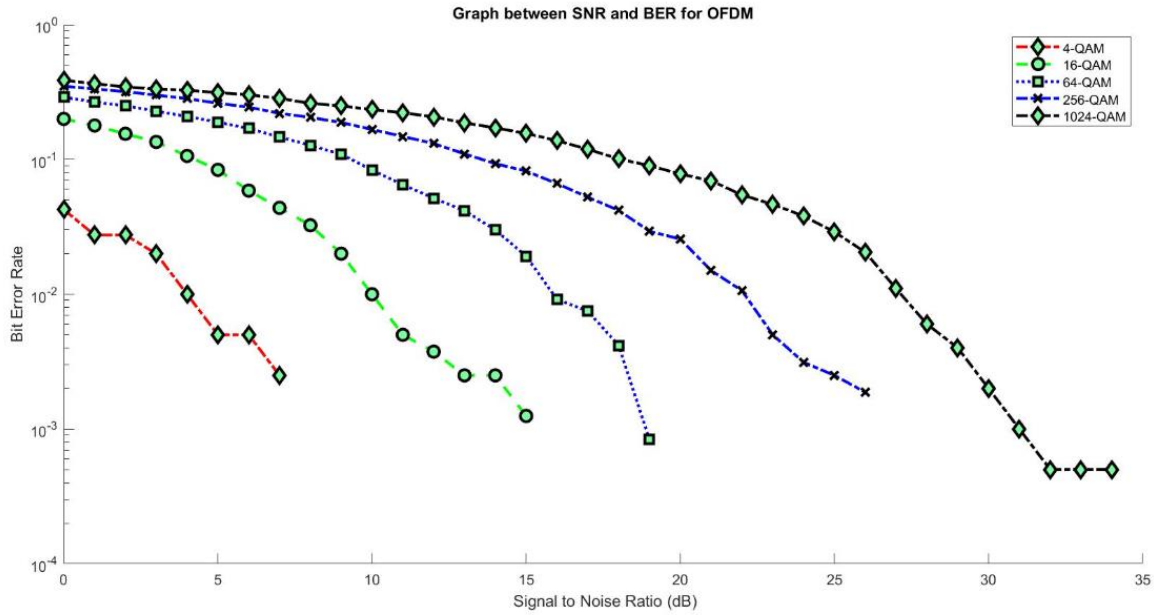


Figure 4.29: BER 512 OFDM

For a system to be useful, its error probability must be smaller than 10-6, and the simulation of the OFDM system reveals that it achieves this condition. The OFDM's BER plot is presented in Fig. 4.29 above.

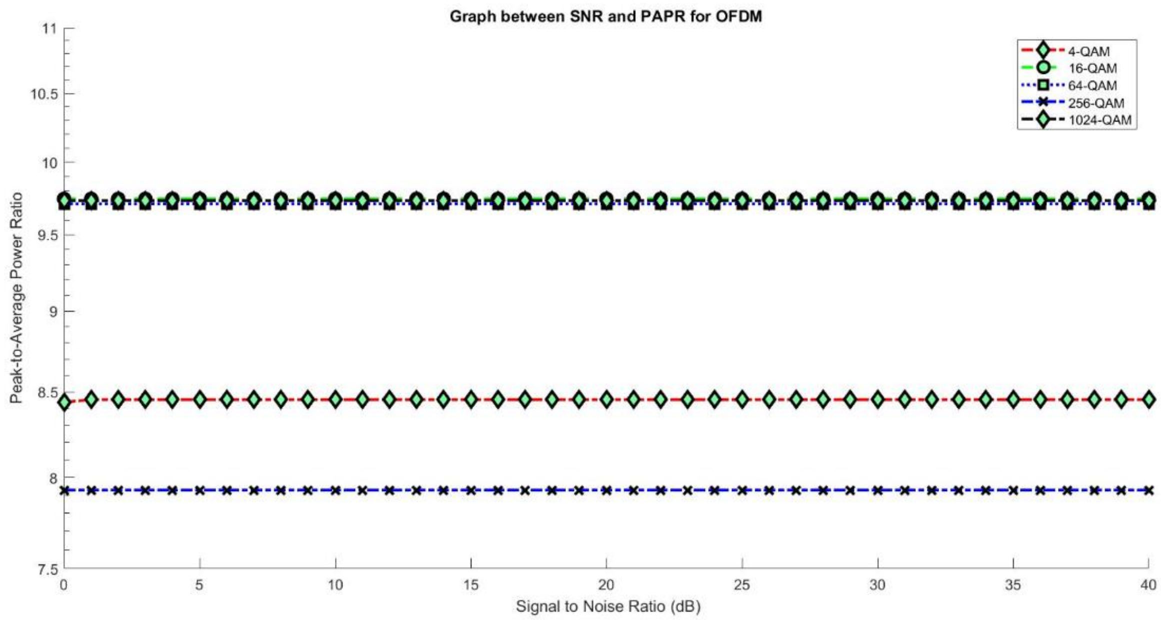


Figure 4.30: PAPR 512 OFDM

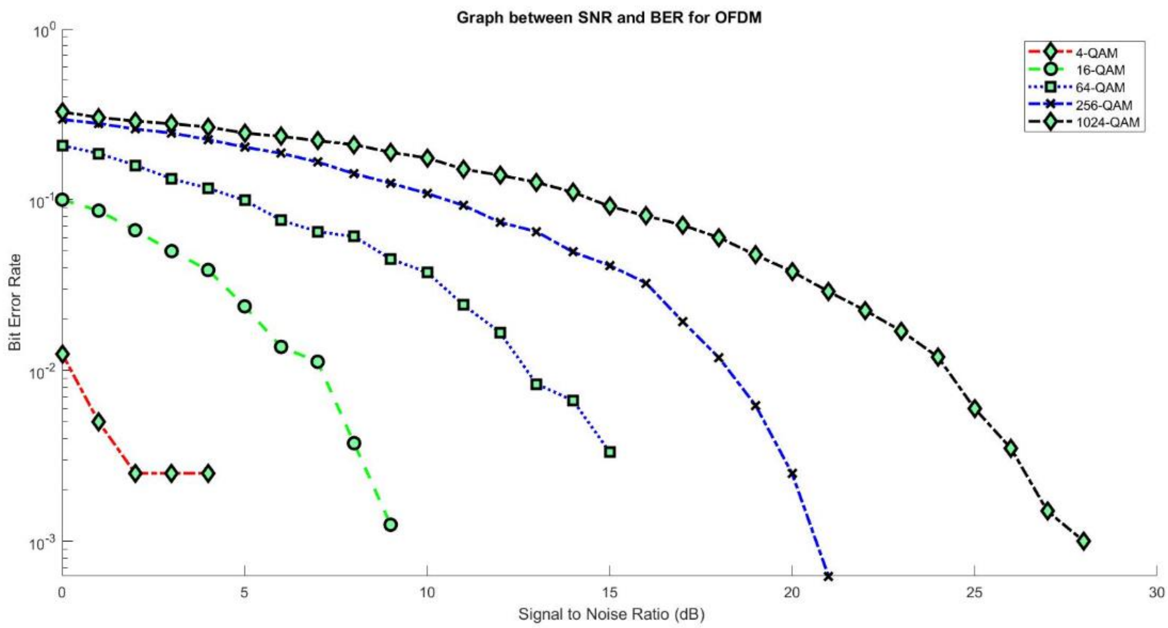


Figure 4.31: BER 1024 OFDM

For a system to be useful, its error probability must be smaller than 10-6, and the simulation of the OFDM system reveals that it achieves this condition.

The OFDM's BER plot is presented in Fig. 4.31 above.

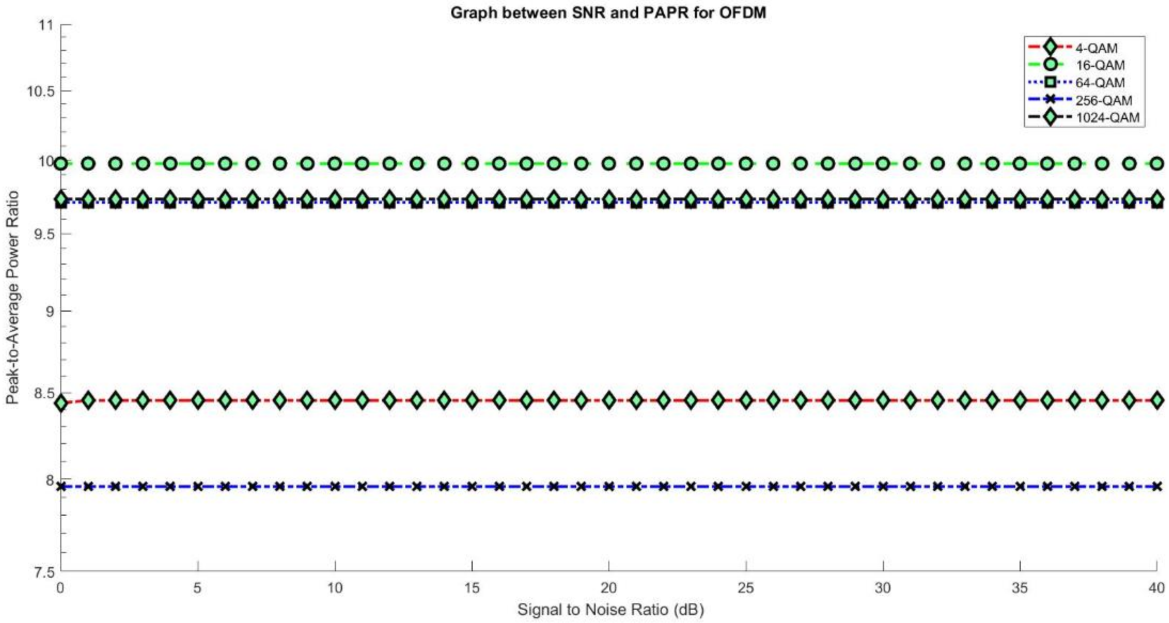


Figure 4.32: PAPR 1024 OFDM

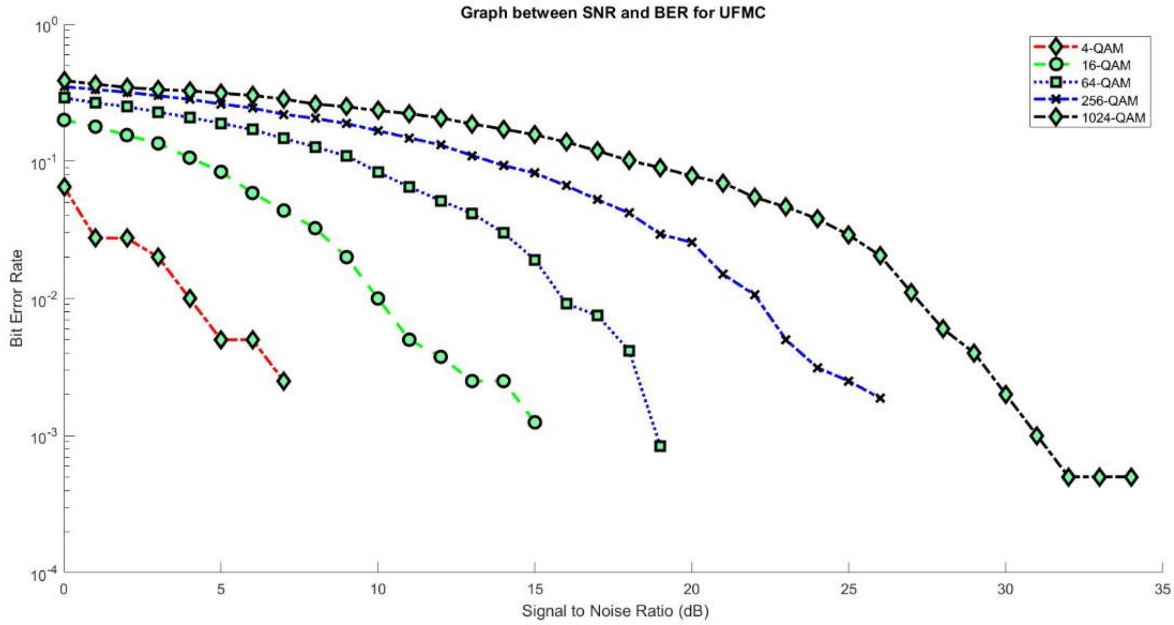


Figure 4.33: BER 512 UFMC

Diagram 4.33 In comparison to lower order QAM, higher order QAM has a greater signal to noise ratio. A proposed multi-carrier solution for future cellular networks is universal filtered multi-carrier (UFMC). Low latency, frequency offset resilience, and decreased out-of-band (OOB) emission all contribute to improved spectral efficiency with UFMC. UFMC, on the other hand, has a difficulty with a high peak-to-average power ratio (PAPR)

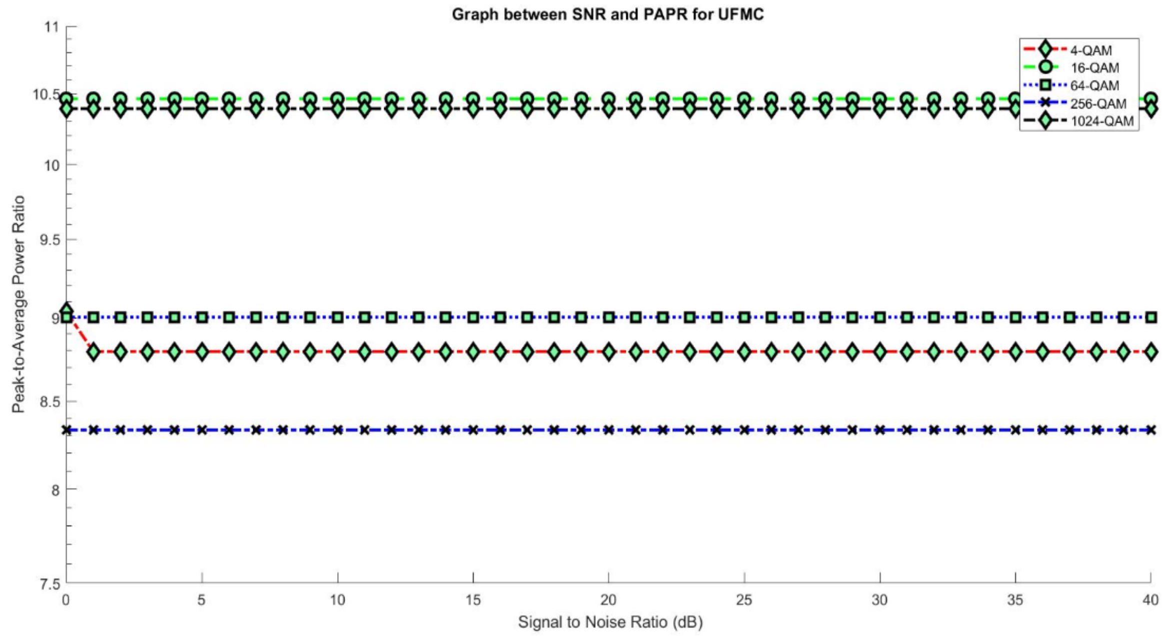


Figure 4.34: PAPR 512 UFMC

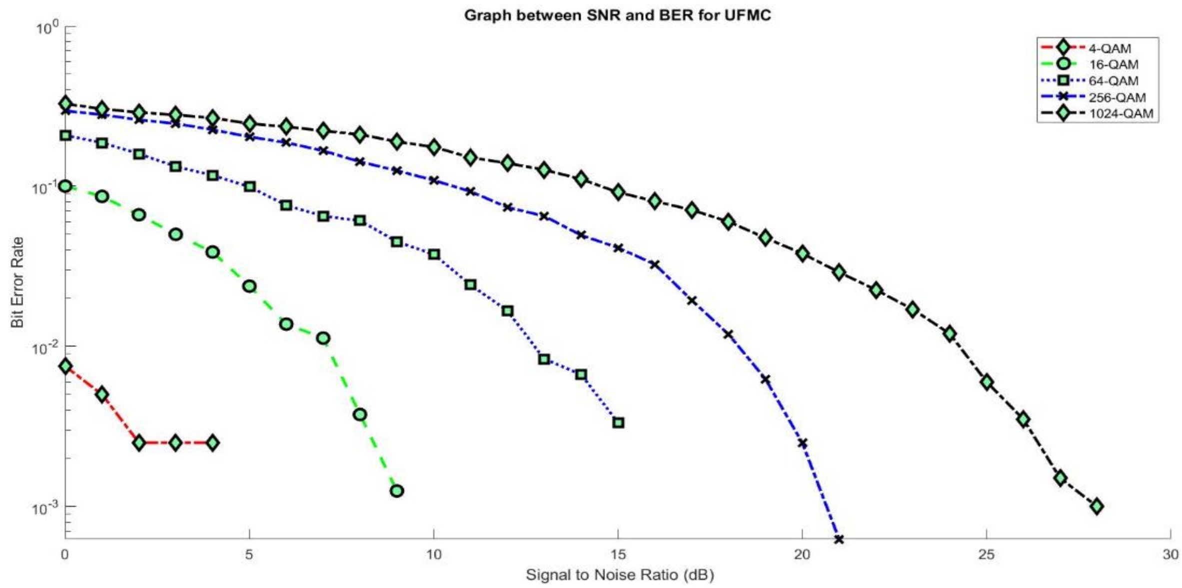


Figure 4.35: BER 1024 UFMC

In comparison to lower order QAM, higher order QAM has a greater signal to noise ratio. A proposed multi-carrier solution for future cellular networks is universal filtered multi-carrier (UFMC). Low latency, frequency offset resilience, and decreased out-of-band (OOB) emission all contribute to improved spectral efficiency with UFMC. UFMC, on the other hand, has a difficulty with a high peak-to-average power ratio (PAPR)

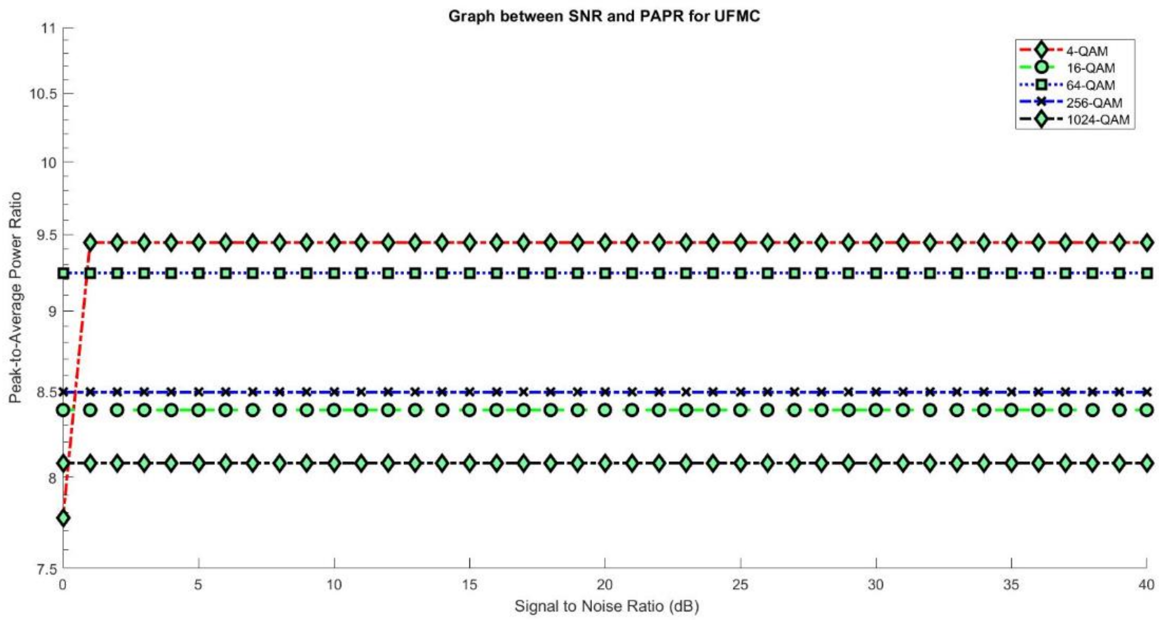


Figure 4.36: PAPR 1024 UFMC

Table 4.1 Signal to noise ratio Vs BER of UFMC

	BER_UFMC					
SNR(**dB**)	5	10	15	20	25	30
4-QAM	0	0	0	0	0	0
16-QAM	0.0375	0.0025	0	0	0	0
64-QAM	0.12	0.034167	0.001667	0	0	0
256-QAM	0.20375	0.11125	0.038125	0.0025	0	0
1024-QAM	0.262	0.1875	0.102	0.0465	0.003	0

Table 4.2 Signal to noise ratio Vs BER of FBMC

	BER_FBMC					
SNR(dB)	5	10	15	20	25	30
4-QAM	0.009692	0	0	0	0	0
16-QAM	0.112065	0.023832	0.000299	0	0	0
64-QAM	0.209988	0.108979	0.031812	0.001226	0	0
256-QAM	0.283664	0.191418	0.102255	0.036182	0.002704	0
1024-QAM	0.328402	0.255511	0.175877	0.09817	0.039094	0.004732

Table 4.3 Signal to noise ratio Vs BER of FOFDM

	BER_F-OFDM					
SNR(dB)	5	10	15	20	25	30
4-QAM	0	0	0	0	0	0
16-QAM	0.015	0	0	0	0	0
64-QAM	0.083333	0.013333	0	0	0	0
256-QAM	0.17	0.07625	0.03	0.000625	0	0
1024-QAM	0.2325	0.149	0.0805	0.141	0.1125	0

Table 4.4 Signal to noise ratio Vs BER of OFDM

	BER_OFDM					
SNR(dB)	5	10	15	20	25	30
4-QAM	0	0	0	0	0	0
16-QAM	0.0375	0.0025	0	0	0	0
64-QAM	0.12	0.034167	0.001667		0	0
256-QAM	0.20375	0.11125	0.038125	0.0025	0	0
1024-QAM	0.262	0.1875	0.112	0.1465	0.113	0

Table 4.5 Signal to noise ratio Vs PAPR of UFMC

	PAPR_UFMC					
SNR(dB)	5	10	15	20	25	30
4-QAM	7.932962	7.932962	7.932962	7.932962	7.932962	7.932962
16-QAM	8.751509	8.751509	8.751509	8.751509	8.751509	8.751509
64-QAM	7.909838	7.909838	7.909838	7.909838	7.909838	7.909838
256-QAM	7.71699	7.71699	7.71699	7.71699	7.71699	7.71699
1024-QAM	6.227781	6.227781	6.227781	6.227781	6.227781	6.227781

Table 4.6 Signal to noise ratio Vs PAPR of FBMC

	PAPR_FBMC					
SNR(dB)	5	10	15	20	25	30
4-QAM	7.582214	7.582214	7.582214	7.582214	7.582214	7.582214
16-QAM	8.853431	8.853431	8.853431	8.853431	8.853431	8.853431
64-QAM	7.913023	7.913023	7.913023	7.913023	7.913023	7.913023
256-QAM	8.574292	8.574292	8.574292	8.574292	8.574292	8.574292
1024-QAM	7.759556	7.759556	7.759556	7.759556	7.759556	7.759556

Table 4.7 Signal to noise ratio Vs PAPR of FOFDM

	PAPR_F-OFDM					
SNR(dB)	5	10	15	20	25	30
4-QAM	11.07898	9.625122	10.99662	8.922642	10.65097	10.16609
16-QAM	8.955818	9.905865	9.443617	11.37443	10.04172	9.102794
64-QAM	10.45266	10.5532	10.68746	10.21901	11.0092	10.25463
256-QAM	8.760272	9.128639	9.922805	9.316024	9.73646	9.694711
1024-QAM	9.123188	9.773929	10.53767	11.36878	8.894334	11.07352

Table 4.8 Signal to noise ratio Vs PAPR of OFDM

	PAPR_OFDM					
SNR(dB)	5	10	15	20	25	30
4-QAM	7.906134	7.906134	7.906134	7.906134	7.906134	7.906134
16-QAM	9.829017	9.829017	9.829017	9.829017	9.829017	9.829017
64-QAM	8.912485	8.912485	8.912485	8.912485	8.912485	8.912485
256-QAM	8.614157	8.614157	8.614157	8.614157	8.614157	8.614157
1024-QAM	7.788972	7.788972	7.788972	7.788972	7.788972	7.788972

Refer to UFMC vs. OFDM Modulation for an example that describes the Universal Filtered Multi-Carrier (UFMC) modulation scheme.

FBMC is considered advantageous in comparison to OFDM by offering higher spectral efficiency. Due to the per subcarrier filtering, it incurs a larger filter delay (in comparison to UFMC) and also requires OQAM processing, which requires modifications for MIMO processing.

Refer to FBMC vs. OFDM Modulation for an example that describes the Filter Bank Multi-Carrier (FBMC) modulation scheme. The F-OFDM vs. OFDM Modulation example describes the Filtered-OFDM modulation scheme.

UFMC is considered advantageous in comparison to OFDM by offering higher spectral efficiency. Sub band filtering has the benefit of reducing the guards between sub-bands and also reducing the filter length, which makes this scheme attractive for short bursts. The latter property also makes it attractive in comparison to FBMC, which suffers from much longer filter length.

For an example of the Filter Bank Multi-Carrier (FBMC) modulation method, see FBMC vs. OFDM Modulation. The Filtered-OFDM modulation strategy is described in the F-OFDM vs. OFDM Modulation example. In compared to OFDM, UFMC is preferred because it has higher spectrum efficiency. Sub band filtering has the advantage of lowering barriers between sub bands while simultaneously shortening the filter length, making it ideal for brief bursts.

In compared to FBMC, which has a much longer filter length, the latter attribute makes it appealing.

Multicarrier modulation is a key feature of the physical layer system of 5G technology. In this work, four prominent multicarrier strategies such as F-ODDM, OFDM, FBMC and UFMC have been simulated and their characteristics have been studied. The performance of each technique has been compared with conventional CP-OFDM. In this work two performance metrics such as PAPR and BER were studied. From this work of evaluating the performance of prominent modulation techniques it has been observed that one method shows better performance in one aspect than the other method but the other method proves to be superior in the other aspect. The next generation mobile network is in the process of development and it has not yet been decided which waveform strategy will win. Other parameters should be adapted to further work.

Here, we compared the four multiplexing and multicarrier techniques F-OFDM, OFDM, FBMC and UFMC by considering some parameters. By looking at the graphs we could say FBMC, UFMC is far better than the OFDM and F-OFDM. In this respect, different modulation schemes can also be established through wireless communications.

5. CONCLUSION AND FUTURE WORK

5.1. Conclusion

In this thesis, the performances like PAPR, power spectral density and BER of new waveform candidates such as FBMC, UFMC OFDM and F-OFDM for 5G mobile communication systems have evaluated. The simulated results have show that UFMC is considered advantageous in comparison to other considered methods by offering higher spectral efficiency. In addition, also compared their PAPR and BER. It have observed from all numerical results that PAPR and BER of three waveform candidates is higher than that of UFMC.

Due to its simplified architecture and the obtained values of PAPR and PSD, the FBMC appears to be the best compromise. Nevertheless, a complete performance evaluation requires the determination of the BER in Additive White Gaussian Noise AWGN as well as the Rayleigh and Rician Fading Channel, with considering the complementary cumulative distribution function.

5.2. Future Scope

The Data traffic can be increased by approximately 30 % and cannot be covered by current mobile technologies. There is also a prerequisite for the wireless networking of the next generation (5G). The objective of which is to provide a high capacity and data rate at 1TBps. The required ability and data rate can be achieved by choosing a better modulation technology. The successor to the 3G technology is to 4G, which is used as a modulation technology that is OFDM which provides Ultra-wide band access to a mobile device with more bandwidth, data and better service compared to 3G mobile. The Advance FBMC and UFMC MIMO systems cannot address the problem of the spectrum shortage on its own; Cognitive radio needs to be combined with mobile systems for the next generation applications.

6. REFERENCES

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