Performance analysis of diverse waveform for 5G

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By

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CERTIFICATE

This is to certify that Rajwinder Kaur bearing Registration no. 11613493 have completed objective formulation/Base Paper implementation of the thesis titled, **“Performance analysis of diverse waveform for 5G”** under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of thesis has ever been submitted for any other degree at any university.

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DECLARATION

I, Rajwinder Kaur, student of M. Tech under Department of Electronics and Communication of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-I report is based on my own intensive research and is genuine.

This report does not, to the best of our knowledge, contain part of my work which has been submitted for the award of my degree either of this University or any other University without proper citation.

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ABSTRACT

Multicarrier techniques are gaining more attention to provide larger data rate in future radio communication system. Today the numbers of users are increasing day by day and to provide the best services, more efficiency to users, the more reliable techniques are needed. There are two techniques for modulation, one of them is OFDM. Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier technique which divides the total available bandwidth into subcarriers. It uses the cyclic prefix to reduce the interference between the two or more adjacent carriers and it also makes use of the available bandwidth efficiently. It provides the good spectral efficiency with lower PAPR (Peak to Average Power Ratio). FBMC is a modulation technique which overcomes the various limitations of already existing techniques like PAPR problem in OFDM, intersymbol interference etc. FBMC is a derivative of OFDM. Basically, the FBMC is also a modulation and multiplexing multicarrier scheme and it is used to reduce the inter-channel interference in LTE, which is the major problem in the wireless networks and increases the bandwidth efficiency using filter banks to eliminate the interference of the subcarriers instead of using guard interval between two or more subcarriers.

In the planning of 5G physical layer selection of the correct waveform for it is very important factor. New coming waveforms must be able to deal with the large number of consumers, large data production and also it should give more effective use of vacant bandwidth to deal with the perception of 5G "everything everywhere and ever connected" with view of boundless capacity. Despite Orthogonal Frequency Division Multiplexing (OFDM) has been used during the time of transmission waveform in wired and wireless structures, but OFDM has certain disadvantages which make it incompatible for the future use in 5G air interface. OFDM has been used in 4G systems very well, but due to the problem of PAPR (Peak to Average Ratio) and use of cyclic prefix (CP), it is not useful in 5G systems. To deal with 5G system new modulation techniques are required such as FBMC.

The radio systems are sensitive to the different types of fading and high signal to noise ratio is desired for better performance. Therefore, various coding techniques can be used such as block coding, convolutional coding, concatenated encoding etc. However, the digital modulation techniques are used to modulate the digital data, so that it can be transmit over large distances. The various modulation techniques are QPSK, PSK, BPSK, QAM, OQAM etc. The purpose of this whole discussion is the OFDM and FBMC modulation techniques and encoding techniques for the better diverse waveform for 5G.

LIST OF ABBREVIATIONS

OFDM	Orthogonal Frequency Division Multiplexing
FBMC	Filter Bank Multicarrier
OQAM	Offset Quadrature Amplitude Modulation
PAPR	Peak to Average Power Ratio
CP	Cyclic Prefix
UMTS	Universal Mobile Terrestrial System
AM	Amplitude Modulation
PM	Phase Modulation
FM	Frequency Modulation
BPSK	Binary Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
FDM	Frequency Division Multiplexing
RF	Radio Frequency
WLAN	Wireless Local Area Network
WiMax	World Wide Interoperability for Microwave Access
GSM	Global System for Mobile
CDMA	Code Division Multiple Access
DSL	Digital Subscriber Line
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform

FFT	Fast Fourier Transform
SLM	Selective mapping scheme
PTS	Partial Transmit Sequence
TR	Tone Reservation
PTS	Partial Transmit Sequence
IC	Interference Cancellation
ISI	Inter-Symbol Interference
SDMA	Spatial Division Multiple Access
QOS	Quality of Service
ICI	Inter-Carrier Interference
VSB	Vestigial Side-Band Modulation
PPN	Poly-Phase Network
MMSE	Minimum-Mean-Square-Error
CMT	Cosine Modulated Multi Tone
DFE	Decision Feedback Equalization
CFC-FBMC	Circular Fast Convolution-Filter Bank Multicarrier

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CHAPTER - 1 INTRODUCTION

1.1 An Overview:

Wireless communication is the process of exchanging the data or information over the distance without using wires, cables or any other form of electrical conductors. Wireless is a big term today which allows using the RF or electromagnetic waves as a medium. Radio frequency waves are used to carry information or data as a medium for that data. Wireless means there is no need of physical connection such as wires or cables between transmitter and the receiver to transfer any information or to exchange data over the distance.

In these days, the mobile devices or wireless devices connecting to the internet are increasing very fast. To provide the better services to these devices is very important task for the incoming technology. There are many waveforms available for 5G. Out of them, one is OFDM (Orthogonal Frequency Division Multiplexing). OFDM divides the total available bandwidth into different subcarriers. To reduce the interference and to increase the spectral efficiency, ODM use the Cyclic Prefix (CP).OFDM have various problems like high PAPR (Peak to average Power Ratio). To overcome this problem FBMC comes into existence. FBMC (Filter Bank Multicarrier) with OQAM (Offset Quadrature Amplitude Modulation) which is the extension or type of the recent OFDM (Orthogonal Frequency Division Multiplexing) increases the spectral efficiency and reduce the PAPR. The FBMC/OQAM provides the better spectral efficiency as compare to OFDM and also useful to gives the high data rates. However, FBMC/OQAM reduces the adjacent channel interference using filter banks and the number of users can use or share the spectrum simultaneously.

1.2 Rationale of Study

This paper deals with the FBMC modulation and multiplexing technique. Here, the motive of this study is to provide the better services to each user, because the number of users is increasing day by day with very fast rate. To increase the data rate and spectral efficiency in next generation or in 5G systems, there should be efficient techniques available. Therefore, we are concentrating on FBMC to increase the performance in future system and to eliminate the interference between two or more carriers. In this paper, we will study about the different diverse channel waveforms for the 5G systems. The focus of this paper is on the FBMC transmitter part and FBMC receiver part and how it can be used to draw the future 5G waveforms. And we also had taken the OFDM in consideration to understand the difference between OFDM and FBMC. That means we discussed in this paper why we needed FBMC if we already have the OFDM. To mitigate the computational complexity we used the multiple level of filter banks.

1.2 Aim and Objective:

To deal with the speed of the wireless systems in these days is a challenge. OFDM and FBMC are the candidate waveforms for the 5G system. So to check the performance of the waveforms to increase the speed the different methods should apply. Different parameters are required to change and to check the performance of the system. 5G diverse waveforms are required to check the efficiency of the future system. This paper is concentrating on these waveforms only to get the best waveform for future system.

1.4 Single carrier vs Multicarrier:

In one carrier transmission one Radio Frequency carrier is given to keep the data. So, data as bits is conveyed by one single RF carrier. Moreover, the single modulation techniques are AM (Amplitude Modulation), PM (Phase Modulation), FM (Frequency Modulation), BPSK (Binary Phase Shift Keying) and QPSK (Quadrature Phase Shift Keying) , in which the information is modulated over a single carrier. OFDM, otherwise called as multicarrier transmission or modulation, utilizes various more than one carrier signals at various frequencies, sending a portion of the bits on each channel. This is like FDM (Frequency Division Multiplexing) however on account of OFDM; the majority of the sub channels are devoted to a single information source. In case of OFDM, IFFT is utilized at the transmitter to finish this, which is not possible in Single carrier case.

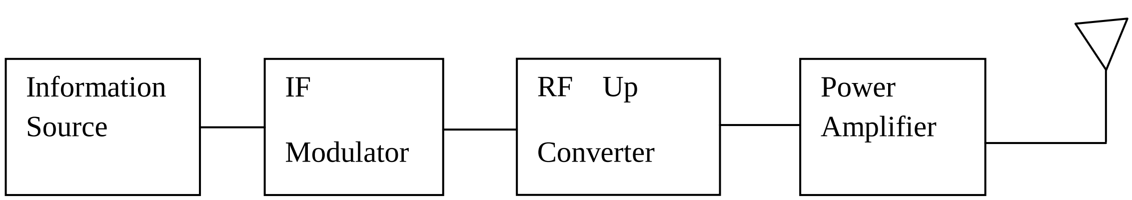


Fig.1.1. Single Carrier System

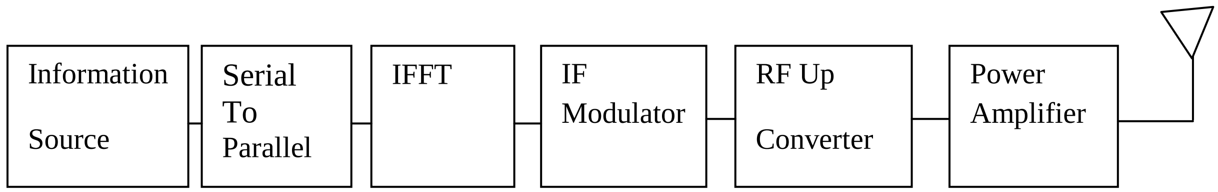


Fig.1.2. OFDM based Multicarrier System

As appeared in the figure 1.1, single carrier network data as voice or information is superimpose on single RF carrier frequency. This superimposed IF signal is changed over to the superimposed on one RF frequency. This is strengthening utilizing RF power intensifier previously being transmitted over the air utilizing the receiving wire or antenna. Single carrier conveys information bits in view of modulation design used in the modem. For BPSK 1 bit is mapped on this carrier, for QPSK 2 bits, for 16QAM 4bits and for 64QAM 16 bits etc.

Satellite correspondence structures, GSM, CDMA and other wireless schemes utilize one carrier for transportation of data and gathering of data. Dissimilar to single carrier structure, Orthogonal Frequency Division Multiplexing utilizes numerous carriers distributed very near over the band. All carriers brings information bits according to modulation scheme engaged. Subsequently Orthogonal Frequency Division Multiplexing conveys information rate is greater over the single carrier scheme. Orthogonal Frequency Division Multiplexing procedure is utilized as a part of WLAN (Wireless Local Area Network) and Wimax (World Wide Interoperability for Microwave Access) broadband innovations.

1.5 Concept of Orthogonality

In arithmetic, orthogonality is the connection of two lines at right edges to each other, and the speculation of this connection into n measurements; and to a number of arithmetic connections thought of as depicting non-interfering, uncorrelated, or free objects of few types. The idea of orthogonality has been extensively summed up in arithmetic, science, and building, particularly since the start of the sixteenth century. Quite a bit of it has included the ideas of scientific capacities, math, and direct polynomial math.

In Orthogonal Frequency Division Multiplexing the subcarrier beat utilized for transmission should be rectangular. This has the pros that the assignment of pulse building and modulation can be achieved by a straightforward Inverse Discrete Fourier Transform (IDFT) and it can be actualized effectively as an Inverse Fast Fourier Transform. In like manner in the theorems we just required a FFT to invert this action. As indicated by the theorems of the Fourier Transform the rectangular beat shape will prompt a sin(x)/x sort of range of the subcarriers.

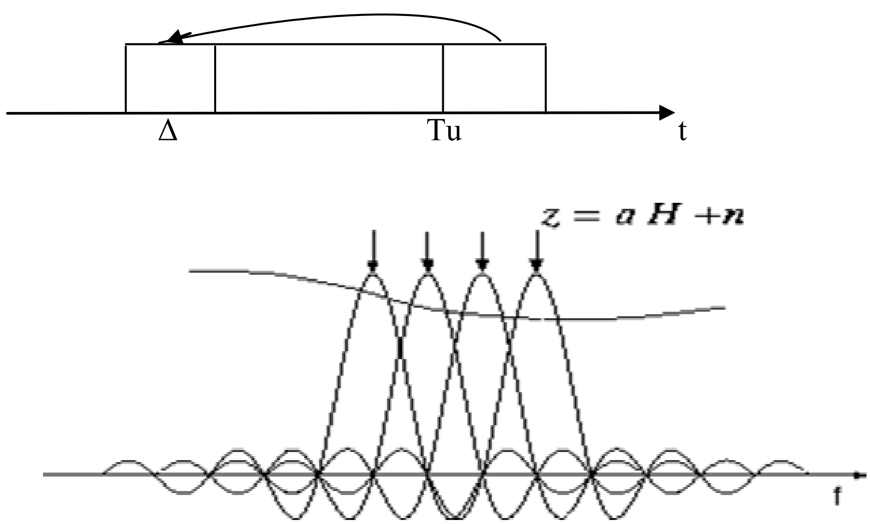


Fig.1.3. Concept of Orthogonality

Obviously the spectrums of the subcarriers are not separated but overlap. The reason why the information transmitted over the carriers can still be separated is the so called orthogonality relation giving the method its name. By using an IFFT for modulation we implicitly chose the spacing of the subcarriers in such a way that at the frequency where we evaluate the received signal (indicated as arrows) all other signals are zero. In order for this orthogonality to be preserved the following must be true:

1. The receiver and the transmitter must be perfectly synchronized. This means they both must assume exactly the same modulation frequency and the same time-scale for transmission (which usually is not the case).

2. The analog components, part of transmitter and receiver, must be of very high quality.
3. There should be no multipath channel.

In particular the last point is quite a pity, since we have chosen this approach to combat the multipath channel. Fortunately there's an easy solution for this problem: The OFDM symbols are artificially prolonged by periodically repeating the 'tail' of the symbol and precede the symbol with it at the receiver this so called guard interval is removed again. As long as the length of this interval Δ is longer than the maximum channel delay T_{max} all reflections of previous symbols are removed and the orthogonality is preserved. Of course this is not for free, since by preceding the useful part of length T_u by the guard interval we lose some parts of the signal that cannot be used for transmitting information.

1.6 OFDM (Orthogonal Frequency Division multiplexing)

This is a multicarrier technique in which the available bandwidth is shared among individual modulated data sources. However, the single modulation techniques are AM, PM, FM, BPSK and QPSK, in which the information is modulated over a single carrier. OFDM is a broadband technology which support data rate in form of 100 megabits per second. Orthogonal Frequency Division Multiplexing is technique which gives the general idea to divides the total available bandwidth into sub-channels. These sub channels are orthogonal with each other. OFDM is a method of encoding data on multiple carrier frequencies. OFDM is combination of modulation and multiplexing. It has developed into a popular scheme for widespread digital communication, used in applications such as digital TV and audio broadcasting, DSL internet access, wireless networks, power line networks and 4G mobile communication. OFDM overcome the problem of large bandwidth requirement. In OFDM, cyclic prefix is used to reduce the interference. To overcome the effect of multipath fading problem this occurs in UMTS.

1.7 Need of Channel Coding in OFDM

Channel coding is very important to analyses the response of OFDM. In any modulation technique, the performance cannot be achieved without using any coding. The radio system experience the fading, higher signal to noise ratio is needed to get the feasible error probability.

Moreover, the interference is also a serious problem in wireless mediums. Large constellation sizes are used in wired systems to achieve the high data rate. In this case coding play a vital role to achieve this much higher data rates in the presence of the crosstalk and interference. Good coding method is very important for digital communication channel. An engineer should take various key points into consideration. These include the factors like gain of cannel, behavior of channel, source coding conditions, modulation etc. Coding in OFDM frameworks has an extra measurement. It can be executed in time and recurrence space with the end goal that the two measurements are used to accomplish better protection against recurrence and time selective fading. So that we can say that the channel coding is very important in every modulation technique to increase the performance of the system.

1.8 Organization of Thesis

This thesis consists of total five chapters which are organized as below:

Chapter 1: Introduction, it is consisting of an overview, the rationale of study, scopes and objectives of the study, introduction to OFDM system, then a brief introduction about the need of channel coding techniques in OFDM

Chapter 2: Literature Review, the study of work done in the field of OFDM/FBMC systems and effects of ISI and ICI on the system is discussed; research papers of related field in sequence are also discussed.

Chapter 3: 5G systems, in this chapter the basic concepts of OFDM system along with PAPR reduction techniques, benefits of OFDM system, OFDM channel coding techniques, modulation technique and applications have been discussed in detail. OFDM system model also discussed. The research methodology used is also discussed.

Chapter 4: Results and Discussion, in this chapter the expected outcome of the study is discussed. All the results simulated in MATLAB-2015 has been discussed for the various FFT size, starting with AWGN channel for our model, OFDM modulation technique and FBMC modulation technique. A complete analysis of BER is presented for the various modulation techniques.

CHAPTER - 2 Literature Review

The transmitter and receiver implementation of OFDM in MATLAB is explained by S.S.GHORPADE et.al [1]. OFDM is intended to cope with the impact of multipath propagation, by portioning the wideband frequency selective fading channel into some narrow band flat fading channels. To bypass the inter-symbol interference OFDM use the guard bands between the sub-carriers to keep them separate from each other. Using 64 sub-carriers less processing time is required and complexity is also less. Spectral efficiency increased and peak to average power ratio is reduced using power amplifiers, and many other techniques can be used to reduce PAPR as clipping, scrambling, peak cancellation etc. So the multipath fading problem has been solved.

The FBMC techniques used to raise the rate of bits, by reducing the interval of guards and when cyclic prefix is not present as essential in OFDM explained by Lalit Chettri et.al [2]. The future FBMC will enhance the capability and will provide the bandwidth usage in perfect manner. OQAM post-processing in FBMC contains two actions: First one is the multiplication action take place by θ pattern. Secondly OQAM post-processing is conversion of real to complex, and in this symbol with two real valued makes a single complex valued symbol. But this conversion reduces the sampling rate. The full model of FBMC is designed and simulated by the software known as Systemvue 2013.01. In this model random bits are used as the input signal after that these can be converted to the integer. Here, to generate digital modulation signal on baseband Digital Modulation model can be used, which also include the basic modulation schemes. For this 16QAM modulation scheme is used. At the receiver side equalizer is used here to overcome the overlapping problems

The high peak-to-average power ratio (PARP) is the major issue in all multicarrier communication systems introduced by Hanwang et.al [3]. In past time the methods used to reduce the PARP in OFDM were as: clipping and filtering scheme, SLM (selective mapping scheme), PTS (partial transmit sequence) scheme, and TR (tone reservation) scheme, but due to the different structure of FBMC these schemes were not useful for FBMC. A hybrid scheme for FBMC/OQAM signals to reduce the PARP (peak-to-average ratio) and this is depends upon the multi data block PTS (partial transmit sequence) and TR (tone reservation) approaches. Hybrid PTS scheme the data blocks are divided into segment and this is used to optimize every data block signal for which the optimal phase rotation is needed to choose. To achieve this iterative clipping filtering is used to generate peak canceling signal for each segment of signal. This operation is very useful to cancel peak of signals.

Behrouz Farhang-Boroujeny et.al [4] presented the idea of various multicarrier techniques. Firstly, the OFDM (orthogonal frequency division multiplexing) proposed in wireless communication to deal with ISI. It divides the available bandwidth into several subcarriers. Before OFDM technique for synthesis and analysis of multicarrier signals there was another technique that was the use of filter banks. CMT and VSB modulation also proposed with filter banks. In VSB (Vestigial Side-Band Modulation) modulation the given bandwidth spectrum of signal i.e. baseband signal divides into two categories. At positive frequency the first part of baseband signal is choose for modulation of a complex sine wave and at negative frequency second part of baseband signal is used for the modulation of complex sine wave, and demodulation can be achieved by reversing this. The multicarrier technique is useful to compromise with frequency selective channels, in which the gain fluctuations occur across the frequency band which can cause of ISI and ICI. To overcome this problem multicarrier system use the channel equalization mechanism.

To balance the channel drawback between the multiple users with reduced complication and cost of system, Centralized Pre-Equalization is used. So the FBMC perform better than OFDM with pre-equalization, because FBMC uses prototype filters to define time-frequency window of each subcarrier. By using this, the unwanted side lobes can be reduced. This enables the system to jointly add asynchronous CCs from different consumers, services, and locations without interference. The MMSE (minimum-mean-square-error) is used here to obtain the pre – equalization. The shortcoming of use of FBMC is that, there is always an intrinsic imaginary interference present between neighboring sub carriers and symbols, before the pre equalization. It makes preamble design complicate for channel estimation. Mu Xu et.al [5] proposed to compare the efficiency and performance of FBMC and OFDM with centralized pre-equalization and without centralized pre-equalization.

The idea of QAM-FBMC (Quadrature amplitude multiplexing-filter bank multicarrier) demonstrated by Chanhong Kim [6]. The performance of the system shows that the QAM-FBMC gives the lower leakage of spectrum and increased the spectral efficiency against the cyclic prefix-orthogonal frequency division multiplexing (CP-OFDM). Therefore, the FBMC-QAM can provide better solution to 5G waveforms for wireless communication to improve the spectral efficiency of waveforms, there is need to enhance the given time-frequency resources for the provided bandwidth as much as possible. This can be achieved by providing the greater transmission bit rate in time domain and by decreasing the guard interval size in time domain. In FBMC-QAM the symbols of data are mixed together to a per-antenna modulator of FBMC.

Daiming Qu et.al [7] illustrated the filter bank multicarrier with offset quadrature amplitude modulation (FBMC-OQAM) is used to mitigate the peak-to-average power ratio in multicarrier schemes now days. To reduce the PARP there are various techniques developed for OFDM, but these techniques are not useful in FBMC to reduce PARP because FBMC-QAM contains the different structure which is overlapping structure. A partial transmit sequence (PTS) scheme with the use of multi-block joint optimization (MBJO) for PARP reduction for the FBMC-QAM signals. This scheme is also known as MBJO-PTS scheme. MBJO scheme use the structure which is overlapping of the FBMC-OQAM information signal and use the more than one number of blocks for data jointly than the PTS scheme in which optimizing the data blocks independently by dividing each block into several sub blocks and then multiply by rotation factor to reduce the PARP. Joint optimization can handle the situation in which data blocks are overlapping.

Sohail Taheri et.al [8] discussed that how filter bank multicarrier is implementing using the fast Fourier convolution approach. Fast convolution scheme reduce the complexity of the system. There are two convolution methods, these are as overlap-add and overlap-save. In case of overlap-add the zeroes are padded into segment to reach the window length. In overlap-save method, the signal divided into segments to overlapped blocks. By discarding the overlapped part of filtered segments, the final signal can be obtained. The distortion which occurs due to the circular convolution in OQAM signals orthogonal to the body of signal and this can be discarded at the receiver side easily. So the generation of transient of signal does not occur during the modulation process. The reduction in complexity of modulation and demodulation is achieved using CFC-FBMC (circular fast convolution-filter bank multicarrier) scheme. With the high resolution equalization in CFC-FBMC scheme can enable the system to operate in the dispersive environment.

The FBMC-QAM transmission and reception system, adopts the two filters to remove intrinsic interference which occurs due to the overlapping between adjacent sub carriers. One filter used for the sub carrier symbols which are even numbered and another filter is for the sub carrier's symbols used which are odd numbered. After this the several procedures are performed which are as oversampling, IFFT (inverse fast fourier transform) and prototype filtering on each sub carrier symbol which are even numbered and odd numbered. And finally we can get the transmit signal back at the receiver which is overlap and sum block in FBMC. The preamble design can also be used to eliminate the intrinsic interference and preamble use only even number sub carriers in FBMC-QAM. Hyungju Nam et.al [9] proposed a filter-bank multicarrier - quadrature amplitude modulation (FBMC-QAM) system, to transmit QAM symbol with two prototype filters and with orthogonality situation for the FBMC-QAM system in which the intrinsic interference is not present.

Dongkyu Sim et.al [10] explained the layered detection algorithm in order to reduce the residual interference for a filter bank based multicarrier with quadrature amplitude modulation (FBMC-QAM) which occurs due to the multipath fading channels. In this algorithm we use two thresholds: a selection threshold and a region threshold. In the selection threshold, firstly we check that whether there is need of apply interference cancellation or not. In region threshold we divide the sub carriers into two parts, according to their gain of channel. If the gain of channel is above the threshold then we can keep that channel into the group of channels where the gain is maximum and we can detect it successfully without using IC (interference cancellation) algorithm. If the gain of channel is less then we will perform ZF equalization without using IC. Using this algorithm the complexity of detection process can be reducing.

Massive MIMO and filter bank multicarrier are strong approach for design a physical layer of 5G network. The index modulation in multicarriers scheme divides the bit stream into index selection bits. In future the index modulation technique can provide the low complexity and larger efficiency to the single/multicarrier, MIMO systems in 5G communication networks. Due to its flexible system design with active and non active subcarrier which are adjustable by the IM and its immense pros over the multicarrier schemes, it can be possible candidate not only for high speed wireless communication systems, it also can be used in mobile to mobile(M2M) communication systems of 5G network and it needed lower power consumption. Ertugrul Basar [11] proposed the index modulation technique for MIMO and multicarrier communication system for 5G network.

To overcome the problem of interference in FBMC, Hyungsik Han [12] introduced the various techniques. CP-OFDM (Cyclic Prefix - Orthogonal Frequency Division Multiplexing) has some drawbacks so that we use the Quadrature Amplitude Modulation - Filter Bank based Multi-Carrier (FBMC- QAM), which provides the better spectral and bandwidth efficiency. But in FBMC- QAM the interference occurs due to the filters use which are non orthogonal. Thus, to mitigate interference, decision feed- back equalization (DFE) technique is used in FBMC- QAM to cancel residual interference. This scheme is depends upon the preceding and decision feedback equalization block. By using this precoding and decision feedback equalization, we get the response of system which is causal and this response makes the system to mitigate the interference successfully.

R. Razavi et.al [13] analyzed the intrinsic interference which is utilized to increase the spectral efficiency of OFDM/OQAM system. The capability of OFDM/OQAM is evaluated with isotropic orthogonal transfer algorithm (IOTA) pulse shaping through information theoretic analysis. In the past OFDM system, the addition of the cyclic prefix decreased the spectral efficiency of system. So to eliminate this drawback filter bank multicarrier scheme introduced, which increased the efficiency. But now to overcome the drawback of OFDM a algorithm is introduced that is IOTA. To make this successful we analyzed the capacity of OFDM-QAM system with the input Gaussian distribution waveform. After that the effect of ISI and ICI on capacity of system evaluated. Here the intrinsic interference is used instead of discard to improve the channel estimation and to improve the equalization performance at the receiver. Thus, the OFDM-QAM can be used to boost up the power and spectral efficiency in wireless communication.

MIMO used the multiple antennas at transmitter and receiver. Massive MIMO is strong application in FBMC. The massive MIMO mitigate the quantity of subcarriers used in FBMC (filter bank multicarrier). And this helps to decrease the system complexity and delay which occurs by the filter bank at the transmitter which are synthesis and filter bank which are analysis at the receiver. In FBMC systems we assumed that the quantity of subcarriers is very high. So to reduce the symbol rate there will be various problems like reduce bandwidth efficiency, higher peak-to-average power ratio (PAPR). Massive MIMO provide us the solutions of above problems. For this MMSE (minimum mean square error) and MF (matched filter) detectors are used to combine the output at the receiver antennas. In this paper, Arman Farhang et.al [14] discussed the Massive MIMO technology combine with FBMC.

Tero Ihalainen et.al [15] analyzed the use of multirate filter banks. High frequency selectivity, the property of filters can be achieved through the proper design of filter banks. Transmission in FBMC is basically depends on the TMUX configuration with same size of synthesis filter bank and analysis filter bank. The partial synthesis technique permits to construct an uplink transmitter-receiver pair with filter banks of unequal sizes and gives a low-complication of transmitter processing. Using this scheme there is the possibility of doing the interpolation in analog and mitigates the digital to analog conversion sampling rate. At the transmitter side interpolation of samples take place that means the sampling rate can be increased using interpolation at the transmitter side to transmit the signal. At the receiver side inverse process take place. The sampling rate can be reducing using decimation.

FBMC facing the ICI problem due to the phase difference between transmitting antenna between adjacent subcarriers. Because subcarrier transmitted from one transmitting antenna and another adjacent subcarrier transmitted from another transmitting antenna. This cause of inter antenna ICI. Firstly the CDMA based approach and iterative interference cancellation approach used to reduce the inter antenna ICI, but all these approaches increased the computational complexity at the receiver or transmitter. So simple coded alamouti scheme was proposed. Using Alamouti code in filter bank multicarrier, ICI can reduce. It can be achieved by dividing total bandwidth into multiple blocks properly. By using this scheme we can get ICI free output for multipath fading channels. This scheme requires very simple modification in the signal than the existing schemes for obtaining ICI free performance. Therefore, Dongjun Na et.al [16] demonstrated the idea about Intrinsic ICI-Free Alamouti Coded FBMC.

Hyun-Bae Jeon et.al [17] introduced the peak-to-average power ratio (PAPR) mitigation technique for orthogonal frequency division multiplexing (OFDM) signals. OFDM is able to give higher data rate but it have high peak-to-average power ratio (PAPR) problem, due to which it suffers from the out of band radiation when it passes through the devices whose response is non linear, such as high power amplifiers. To mitigate this problem several techniques proposed like clipping and filtering, companding, tone reservation, active constellation extension (ACE) etc. But these techniques increased the complexity of the system. So parabolic peak cancellation (PPC) scheme proposed for efficient complexity. To cancel the peak of the signal, this scheme can apply to the samples whose amplitude is maximum.

Hamid Saeedi-Sourck et.al [18] illustrated the comparison of FBMC (filter bank multicarrier) and OFDM (orthogonal frequency-division multiplexing) in Uplink of Multicarrier Multiple Access Networks. OFDM is a highly sensitive to carrier frequency offset (CFO) between different customers which may increase multiple-access interference (MAI) among different customers, it can cause of using the complex and expensive signal processing and it require to apply interference cancellation methods to mitigate this sensitivity and this makes the system very complicate and does not provide efficient performance to systems. But in case of FBMC we can get perfect performance without increasing the interference cancellation methods to it. FBMC provide the higher efficiency without increasing the complexity of system. Low side lobes filters used in FBMC which reduce the ISI and ICI.

The motive of 5G is to provide very high data rate, better QOS (quality of service) compared to existing 4G LTE networks. The users expected to download data in terabytes annually. The major requirements for initiating 5G are as: this increases the data rate 1 to 10 times than the 4G LTE, it needed to provide connectivity between thousand of devices with higher bandwidth, to provide the connectivity among thousands of devices in IOT 5G networks are required, 5G need to provide the coverage at anywhere, anytime. Small radio wave lengths demand for small size antenna. This can make possible to use large number of small antennas. Directional radiation patterns of antenna provide better protection by using adaptive beam forming schemes, and as a result it gives the reference of Spatial Division Multiple Access (SDMA) or beam forming. In this, the researcher Mamta Agiwal et. al [19] discussed the future of 5G.

Yonghong Zeng et.al [20] explained the FBMC (Filter Bank Multicarrier) duplexing technique. Downlink and uplink send the data at the equal time and with equal frequency band but with the subcarriers which are different. As we know that it is not possible to obtain the full matching in time and frequency with signals downlink and uplink both signals .So that matching errors will ruin the orthogonality between the downlink and uplink. These types of faults make the duplexing in OFDM unstable or unreliable, but in FBMC using the prototype filters the duplexing is very strong to reduce these faults. Duplexing is used to permit two-way communication among two users. Uplink and downlink communication can be occur at the similar time, so we require various tools or system to differentiate the signals to eliminate the interference with each other during transmission. For this purpose we can use the unequal frequencies or unequal time interval, or distinct codes to separate the signals. And we can also separate signals by using another method by composing them orthogonal in a secure domain.

Shihab Jimaa et.al [21] discussed the LTE (long term evolution) and LTE-Advanced which provides the way to reach at the 4G technology. This is the standard developed by the 3GPP (3rd Generation Partnership Project) of UMTS (Universal Mobile Terrestrial System). It increases the capacity and speed of the 4G.The focus is on the LTE requirements, goals, multiple access technology in LTE and MIMO. In OFDM high peak to average ratio, so SC-FDMA was chosen. LTE use the multiple antenna technique i.e. MIMO and use the SC-FDMA (Single Carrier – Frequency Division Multiple Access) modulation scheme in the LTE uplink. LTE-A is further developed to increase the capacity and coverage area and known as 3.9G. LTE use the OFDMA for downlink and SC-FDMA for downlink.

To obtain the suitable waveform for the next generation system i.e. 5G system Behrouz Farhang-Boroujen [22] explained the FBMC technique. In FBMC the filter banks are used, so to design the filters effectively various methods are used. The problems in FBMC as channel equalization, synchronization and tracking methods are explained here to get the solution for them. The FBMC can be choosing to doubly dispersive channels over the OFDM system to obtain the better performance. To implement the FBMC system successfully polyphase structure is used and then compare the complexity of FBMC with the already existing technique i.e. OFDM and the complexity of FBMC transmitter is two times less than the OFDM counterpart and the FBMC receiver complexity is near to but three times less than the OFDM. To get synchronization in system, multiuser cancellation technique can be used but it makes OFDM very complex.

Yanrong Peng et.al [23] explained the FBMC method to demonstrate that the FBMC is more effective then the officially existing procedures like OFDM. Orthogonal Frequency Division

Multiplexing having the extensive band spillage issue and huge PAPR in the framework because of the Doppler impact when the purchasers move ne place to another with fast. Then again FBMC is the method which defeats the confinements of OFDM framework and is the applicant waveform for the cutting edge framework i.e. 5G. the reproduction comes about demonstrates that the execution of FBMC is great when the base station and client gear are set up with single radio wire in the meantime. That implies the execution is great if there should arise an occurrence of SISO frameworks. For the minute the BER estimation of FBMC in the game plan design isn't exceptionally exact which causes the modification of the bend and the mistake in the reproduction comes about.

The three candidate waveforms for 5G Mohammed Abdalla Abdelrahim Ali [24] explained using FBMC, UFMC and OFDM. FBMC is promising while at the same time avoiding the disadvantages. Like FBMC, UFMC is all the more effective to multi-client impediment, demonstrates higher ghostly effectiveness, has prevalent execution just if there should be an occurrence of composed multipoint transmission and is more fit the bill to divided range than OFDM. UFMC improves at short burst/low dormancy transmission circumstances stood out from FBMC and is in a position to convey advanced or complex orthogonality notwithstanding sidestep a couple of traps. The innovative difficulties are mind boggling and require advanced and, undoubtedly, more intricate handset outlines.

Channel Bank Multi-Carrier (FBMC) with Offset Quadrature Amplitude Modulation (OQAM) has been effectively examined for quite a long time. Presently it is likewise a contender for 5G air interface waveform. Hao Lin [25] proposed new tweak arrange named FB-OFDM. This balance conspire has enormously relieved two issues that we identified for customary FBMC plot, to be specific intricacy issue and similarity issue with OFDM. The FB-OFDM plot in reality can to a great extent lessen the extra intricacy w.r.t. OFDM (i.e. under 30%). Additionally, this plan is totally perfect with OFDM. As a matter of fact OFDM can be viewed as one uncommon instance of FB-OFDM. In this manner, all the corresponding strategies, for example, channel estimation, balance, MIMO pre-/disentangling can be direct re-utilized for FB-OFDM without the necessities of extra re-plan exertion.

CHAPTER - 3 Waveforms for 5G

3.1 Background

The utilization of Frequency Division Multiplexing is very old, when multiple lower data rare signals, for example, broadcast, was continued a moderately wide radio band medium utilizing a different carrier recurrence for every data. To encourage partition of the signals at the recipient, the carrier frequencies were divided adequately far separated with the goal that the flag spectra did not interfere. So the output frequency was very low. Rather than conveying separate messages, the distinctive recurrence carriers can hold diverse bits of a solitary higher rate data. The source might be in such a parallel organization, or a serial source can be exhibited to a serial-to-parallel translator whose yield is given to the more than one carriers. In FDM guard bands were used to reduce the interference, so that it was not bandwidth efficient. After that to solve the bandwidth problem, OFDM introduced to reduce the interference and to utilize the bandwidth effectively.

The study about FBMC technique was completed in the middle of 1960s by Chang and Saltzberg. Chang offered the rules which were needed for the indication of the similar values of PAM symbols passing out of filter banks which were overlapping between a minimal radio bands. To send the PAM symbols with effective way, Chang offered the VSB (vestigial sideband) technique for sub-carrier. Saltzberg expanded the idea that how the Chang's mechanism can used for transmission of QAM images in DSB (Double Side Band) form. Effective digital execution of Saltzberg 0multiple carriers structure over polyphase filters was first proposed by Bellanger and after this reviewed by Hirosaki. In 1990, with the promotion in DSL technique much interested activity was developed over discrete multitone (DMT), the similar terminology continually utilized in DSL detail study in spite of Orthogonal Frequency Division Multiplexing. Beforehand, the progress or evolution in this field is an American National Standards Institute (ANSI) gift by Sandberg and Tzannes, it was after broadened and named discrete wavelet multitone (DWMT). Despite the connectivity within this and ancient progression related to filter bank multicarrier kept unlooked for long time. Filtered multitone (FMT) is also a multiple carrier modulation technology that has been especially proposed where DSL use. In reverse of the FBMC techniques which follow the real suggestion given by Chang and Saltzberg, permitting the interference of near subcarrier bands to increase the radio bands effectiveness, FMT works on the traditional

Mechanism of frequency division multiplexing; so that, the subcarrier bands are splitted by guard interval. For this reason, FMT is not much radio bands capable when comparing with FBMC schemes developed by the Chang and Saltzberg.

3.2 Introduction

Orthogonal frequency division multiplexing technique has been used in wireless networks successfully, where it provides the suitable output in multi-path fading. In the event that a high information rate is transmitted over a recurrence selective wireless medium with huge maximal multi-way propagation delay t_{max} correlated with the symbol period, another option to Single Carrier approach is given by the OFDM transmission method. The general thought of the OFDM transmission system is to divide the aggregate accessible radio band into numerous narrowband sub-channels at equal distance frequencies. The sub-channel spectra interfere with each other yet the subcarrier signals are as yet orthogonal. The single high-rate information stream is splitted into some low-rate information streams for the sub-channels. Each sub-channel is modulated separately and will be transmitted at the same time in a superimposed and parallel shape.

FBMC is derivative of OFDM scheme used in wireless communication. It basically consists of the filter banks to reduce the interference between more than one sub carriers, without wasting or without using higher bandwidth. It is more efficient but complexity has increased in this scheme.

Now-a-days UFMC is a highly research involved 5G modulation method. UFMC, a novel multicarrier modulation technique works equivalent to the generality of filtered OFDM and FBMC modulations. Unlike self-subcarrier modulation in FBMC, a group of subcarrier modulation is performed in UFMC. The subcarrier grouping reduces the length of the filter compared with FBMC and also reduces time to perform modulation.

3.4 OFDM System Model

The OFDM is consists of by adding the modulated subcarriers signals transmitted in parallel to IFFT. In general we have transmitted signal $S_n(t)$ for OFDM symbol. Mathematically, each carrier can be described as a complex wave:

$$S_c(t)=A_c(t)\,e^{j|\omega c(t)+\phi c(t)} \tag{3.1}$$

Where

$S_c(t)$ = the real part of original signal.

$A_c(t)$ = the Amplitude

The real signal is the real part of $S_c(t)$. Both $A_c(t)$ and $f_c(t)$, the amplitude and phase of the carrier, can vary on a symbol by symbol basis. The values of the parameters are constant over the symbol duration period t.

As we know OFDM consists of many carriers. Thus the complex signals $S_s(t)$ is represented by:

$$S_s(t)= 1/N \sum_{n=0}^{N=1} A_n(t)e^{j[\omega n\,(t)+\phi n(t)]} \tag{3.2}$$

Where,

$$\omega_n=\omega_0+n\Delta\omega$$

This is in form of continuous signal. If we calculate the waveform of each part or component of signal over a single symbol duration, then the variables $A_c(t)$ and $f_c(t)$ reaction to the not changeable values, which depend upon the frequency of that particular carrier, and so can be written as:

$$\Phi_n(t)=\phi_n \tag{3.3}$$

$$A_n(t)=A_n$$

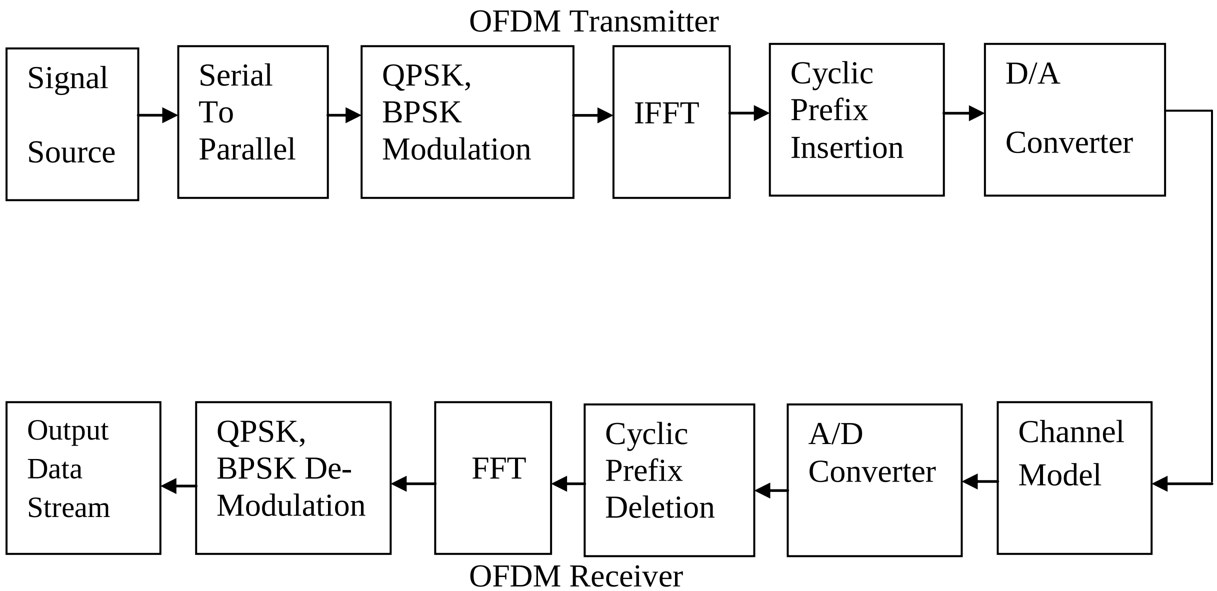


Fig.3.1 OFDM Transmitter and Receiver

If the input data is sampled with the use of a sampling frequency 1/T, then the output data is presented as following:

$$S_s\,(kT)=1/N \sum_{n=0}^{N-1} A_n\, e^{\,j[(\omega_0+n\Delta\omega)kT+\phi_n]} \qquad (3.4)$$

Here, we are bound to the time by which we analyses the signal to N samples. This is suitable than the period of a single data symbol. So, we have a relationship:

$$T=NT$$

By simplifying the equation (3.3) without any loss of quality by assuming ω_0 =0, then we have signal as:

$$Ss(kT)=1/N \sum_{n=0}^{N-1} A_n\, e^{j\phi n\ ej(n\Delta\omega)kT} \qquad (3.5)$$

By comparing the equation (3.4) with Inverse Fourier Transform we get:

$$g(kT)= 1/N \sum_{n=0}^{N-1} G(n/NT)\, e^{j2\Pi nk/N} \qquad (3.6)$$

In equation (3.4), the term $A_n e^{j\phi n}$ is not larger than a explanation of the signal in sampled frequency realm, also $S_s(kT)$ is the time domain image.

OFDM is a multicarrier modulation technique. When multiple of carriers placed near to each other, then it generates the OFDM signal. The sidebands expand out one side, when the modulation of any data or information take place and applied to the carrier. It is the mandatory for the receiver that it should be capable to get the full signal to get original signal back effectively. When signals are sent near to each other they should be situated as that the receiver can differentiate those using filter and there should be guard band among them. But in case of OFDM subcarrier sidebands overlap with each other and they can be received without any interference, because of the orthogonality property. It can be obtained by getting the carrier difference equal to the inverse of symbol duration.

There is a mandatory that the transmitting and receiving system in OFDM should be linear. Because non linearity cause of interference among multiple carriers due to which the inter modulation distortion occurs. And this will also produce unwanted signals which can cause of interference and affects the orthogonality of transmission carriers.

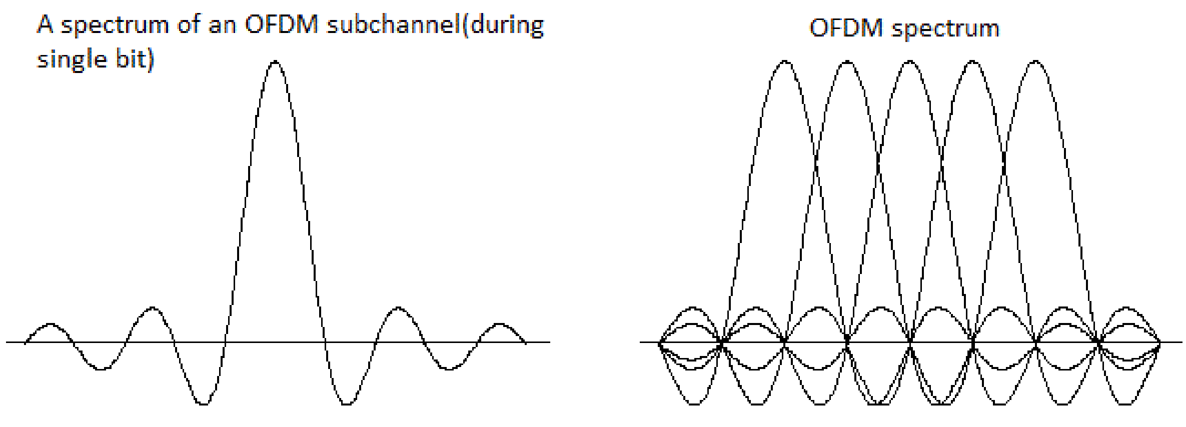


Fig.3.2. OFDM Spectrum

3.3.1 Cyclic Prefix

In broadcast communications, the name cyclic prefix introduces to the prefixing of the symbol, with a recurrence of the end of the symbols. The recipient is ordinarily arranged to reject or remove the cyclic prefix samples, however the cyclic prefix fulfill the two requirements:

- It adds a guard period to cancel the intersymbol interference from the earlier symbol.
- It copies the MSB of the symbol so the linear convolution of a recurrence selective multipath channel can be displayed as circular convolution, which thusly may change to frequency domain by means of a discrete Fourier transform. This access contains basic recurrence domain processing, for example, channel estimation and equalization.

For the cyclic prefix to serve its objectives, it must have a length at least equal to the length of the multipath channel. The concept of a cyclic prefix is traditionally associated with OFDM systems; however the cyclic prefix is now also used in single carrier systems to improve the robustness to multipath propagation.

Utilization of cyclic prefix is very important for the OFDM signal to work properly. The cyclic prefix behaves as a guard interval to preserve the OFDM signals from inters symbol interference. This can be problem in a few conditions even with the much lower information rates that are transmitted in the multicarrier OFDM signal. The fundamental idea driving the OFDM cyclic prefix is very clear. The cyclic prefix is made with the goal that each OFDM signal is preceded by a replica of the end portion of that same signal. Diverse OFDM cyclic prefix lengths are accessible in different systems. For instance inside LTE a typical length and an expanded length are accessible and after Release 8 a third broadened length is additionally included, in spite of the fact that not ordinarily utilized.

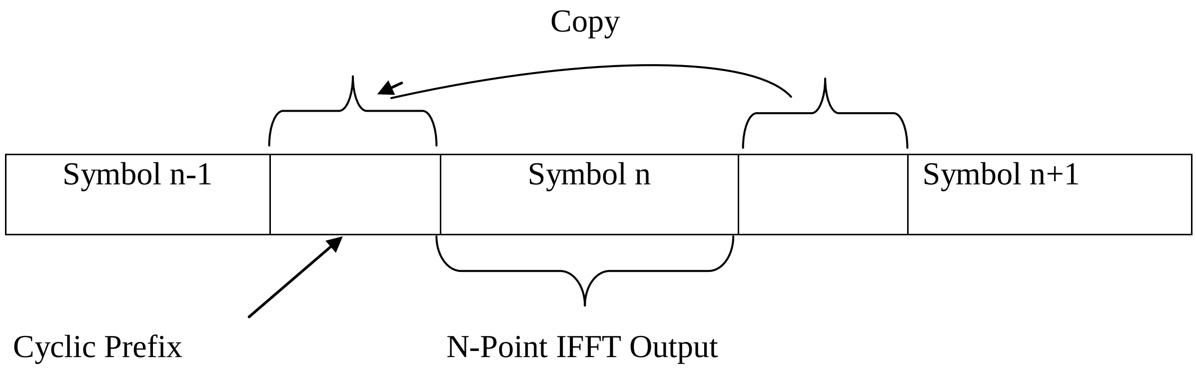


Fig.3.3. OFDM Signal with Cyclic Prefix

3.3.2 PAPR (Peak to Average Power Ratio)

The transmit motions in an orthogonal recurrence division multiplexing (OFDM) scheme can have large values in the time area since numerous subcarrier parts are included through a Inverse Fourier Transform (IFFT) action. Thus, OFDM schemes are familiar to have a large peak-to-average power ratio (PAPR) when contrasted with single-carrier schemes. Generally, the high PAPR is the most negative angles in an OFDM scheme as it diminishes the signal to-quantization quantization noise ratio (SQNR) of the simple analog-digital convertor (ADC) and digital analog convertor (DAC) during reducing the effectiveness of the power amplifier in the transmitter. The PAPR issue is to a greater extent a worry in the uplink since the effectiveness of the power amplifier is basic because of the restricted battery control in a portable terminal.

OFDM is a strategy generally utilized as a part of numerous computerized correspondence schemes such as Digital Television (DTV), Digital Audio Broadcasting (DAB), Terrestrial Digital Video Broadcasting (DVB-T), Digital Subscriber Line (DSL) broadband web get to, benchmarks for Wireless Local Area Networks (WLANs), guidelines for Wireless Metropolitan Area Networks (WMANs), and 4G versatile interchanges. It has many points of interest such as high data rate, solid protection to multipath and large spectral efficiency. Moreover, the most major issues is the high Peak-to-Average Power Ratio (PAPR) of the transmitted OFDM symbols, since this high peaks propose a vast reduction in output or response while a signal coming via a nonlinear High-Power-Amplifier (HPA). The non-linearity of HAP points to in-band emission which expands Bit Error Rate (BER), and out-of-band radiation, which is responsible for neighboring channel interference. There are a few techniques to manage the PAPR issue in OFDM schemes. The diverse procedures can be characterized into various groups as indicated by their qualities. The most common types are: clipping techniques, coding techniques, the distortion less plans with side data and distortion less methods without side data. The least difficult execution strategy is clipping technique, which comprises in to intentionally cut the OFDM signal before amplification. Clipping can decrease PAPR yet this is a nonlinear procedure and may cause both in-band and out-of-band interference while spoiling the orthogonality among the sub-carriers. At that point, coding methods are discovered, which are presented. The key of those systems is to choose the codewords that reduce the PAPR. In the following groups we have the strategies that reason no distortion and make no out-of-band radiation, however they might be require the transmission of the side data to the recipient. Strategies that require the transmission of side data are for instance Partial Transmit Sequence (PTS), Tone Reservation (TR), and so on. Then again Selected Mapping (SLM), Constellation Extension or Orthogonal Pilot Sequences (OPS) don't require the transmission of side data.

3.4 PAPR Reduction Techniques: As we know that the peak to average power ratio is very big problem in OFDM system. Higher PAPR creates many problems in system like increase the complexity of the analog to digital converters and mitigate the efficiency of the RF power amplifier. To overcome the PAPR problem various techniques has been introduced as distortion technique which remove the amplitude of the signal, coding technique and scrambling technique.

3.4.1 Clipping and Peak Windowing

The most straightforward approach to mitigate the peak to average power ratio is to cut the signal, such that the peak of the amplitude restricted to few necessary maximal level. Despite cutting the amplitude is the straightforward idea, there are a couple of issues related with it. First, by altering the OFDM signal amplitude, a type of self-interference is developed that reduces the BER. Second, the nonlinear disturbance of the OFDM signal altogether raises the level of the out-of-band radiation. The last impact can be seen effectively by review the cutting process as a duplication of the OFDM signal by a rectangular window work that equivalents to one if the OFDM amplitude is less than a limit and less than one if the amplitude requires to be cut. The range of the cut OFDM signal is found as the info OFDM range convolved with the range of the window operation. The out-of-band spectral characteristics are specially dictated by the more extensive range of the two, which is the range of the rectangular window work. This range has a moderate move off that is contrarily relative to the frequency.

To treat the out-of-band issue of cut-out, an alternate approach is to increase big signal crests with a specific nonrectangular window. In, a Gaussian-formed window is introduced for this, yet in reality any window can be utilized, provided it has great spectral characteristics. To limit the out-of-band overlapping, in reality the window should be as narrowband as expected. Then again, the window ought not be too long in the TD because the fact that infers that many flag tests are influenced, which expands the BER. Examples of appropriate window capacities are the cosine, Kaiser, and Hamming windows.

3.4.2 Coding and Scrambling

A weakness of previous procedures is that symbols with a high peak to average power ratio go through large corruption of data, so they are more sensitive against errors. To lessen this impact, FEC coding can be used over a few OFDM symbols. By using this, errors due to images with an extensive corruption can be rectified by the neighboring images. In a Orthogonal frequency division multiplexing framework, the probability of occurring error is never again rely on the energy of individual images, yet rather on the energy of various back to back images.

3.4.3 Peak Cancellation

The purpose of each distortion method is mitigation of amplitude of samples whose power increases above the threshold level. In the cutting and peak windowing methods, it was complete via on linear distortion of the OFDM signal, which resultant in a some quantity of out-of-band radiation.

This unwanted impact can be neglected by playing out a peak-cancellation procedure, whereby a time-shifted and scaled-reference work is deducted from the signal; with the end goal that each deducted reference work decreases the highest power minimum one signal sample. By choosing a suitable reference function with roughly the equal radio band as the transmitted data, it can be guaranteed that the highest energy decrease won't cause any out-of-band overlapping of signal. One case of a reasonable reference flag is a sinc work. A limitation of a sinc work is that it has unbounded help. Henceforth, for efficient use, it must be time restricted somehow. One approach to do this without making undesired out-of-band overlapping is to duplicate it by a windowing capacity, for example, a developed cosine window.

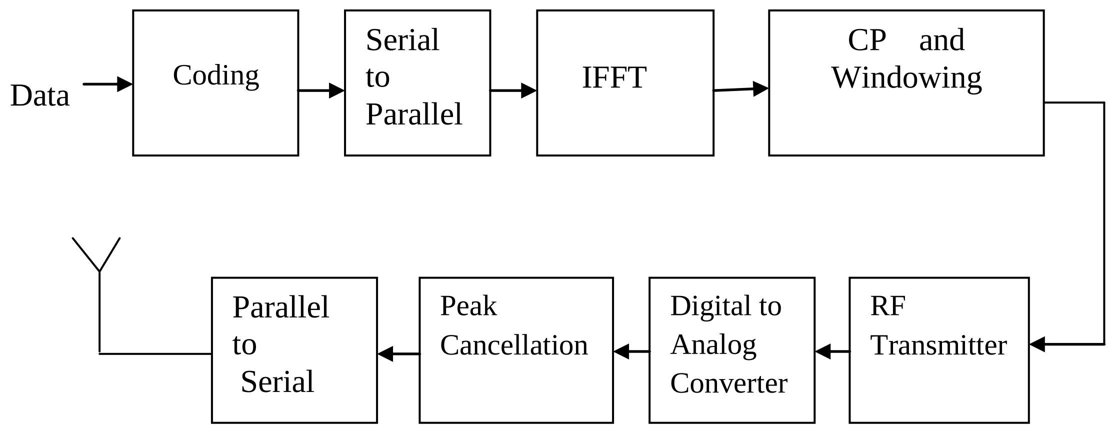


Fig.3.4. OFDM Transmitter with Peak Cancellation

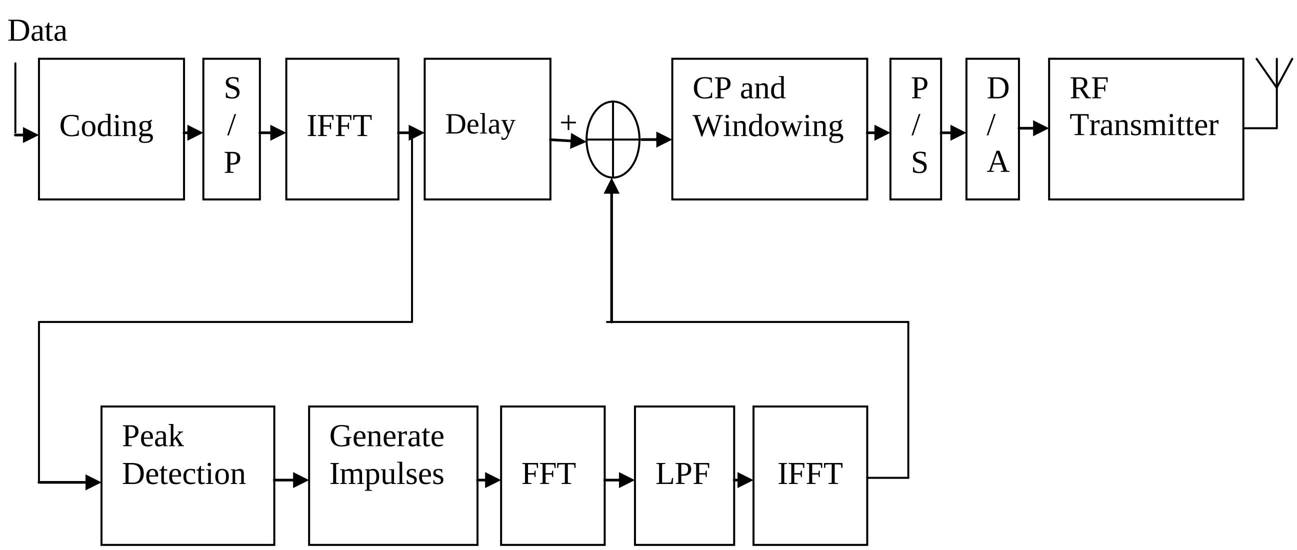


Fig.3.5.Peak cancellation using FFT/IFFT to generate cancellation signal

Pinnacle cancellation can be implemented carefully after origination of the computerized OFDM images. It includes a pinnacle power or amplitude indicator, a comparator to check whether the peak power cross the threshold level and scaling of highest and neighboring samples. Figure 3.5 demonstrates the block diagram of an OFDM transmitter with top cancelation. Input information is first coded and changed over from a serial piece stream to blocks of N complex flag tests. On each of these blocks, an IFFT is implemented. At that point, a cyclic prefix is included, stretching out the image size to N+N G tests. After parallel-to-serial (P/S) transformation, the pinnacle cancelation system is connected to mitigate the peal to average power ratio. It is likewise conceivable to do top cancelation promptly after the IFFT and before the cyclic prefix and windowing. With the exception of the pinnacle cancelation block, there is further no distinction from a standard OFDM transmitter. For the recipient, there is no distinction by any means, so any standard OFDM receiver can be utilized. In the past figures, the pinnacle cancelation was done after P/S transformation of the flag. It is additionally feasible to do the cancelation instantly after the IFFT, as described in Figure 3.6.In this case, the cancelation is done on an image by-image premise. A proficient approach to create the cancelation motion without utilizing a put away reference work is to utilize a low pass filter in the FD. In Figure 3.6, for each OFDM image, the samples that cross some predefined amplitude are identified.

3.4.4 Symbol Scrambling

Symbol scrambling methods to diminish the peak to average power ratio of a transmitted OFDM signal can be viewed as an specific category of peak to average power decrease code. In symbol scrambling technique for every OFDM symbol, the incoming sequence is scrambled via some number of scrambling sequence. So the resulted signal is transmitted with fewer peaks to average power ratio. For unrelated scrambling arrangement, the output OFDM flags and comparing peak to average proportions will be unrelated; therefore if the peak to average proportion for a single OFDM image has a possibility p of crossing a specific level without scrambling, the possibility is diminished to p by utilizing k scrambling codes. Consequently, image scrambling does not ensure a peak to average proportion down some lower limit; rather, it decreases the possibility that high PAPR will happen. It can be see with displayed OFDM spectra for 64 SCs where the backoff is fixed to keep a – 30-dB radio band that is double the – 3-dB radio band. An excellent linear power booster is utilized, which cuts the signal when the resulted power crosses the saturation power limit. The impact of scrambling has been recreated by scrambling the IFFT input information for every OFDM image with a specific number of autonomous corresponding arrangements and choosing the resulted image that provides the littlest PAPR. We can see from that scrambling with 1 and 10 codes gives rather little changes of 0.25 and 0.75dB in the required backoff, individually, contrasted and the case without scrambling.

3.5 Channel Coding in OFDM

Channel coding in digital communication plays a vital role to achieve the maximum data rate in the presence of the crosstalk or any other interference. In OFDM multicarrier technique channel coding is very important to increase the performance of the system. To achieve this OFDM also use some channel coding techniques as given below:

3.5.1 Block Coding

In block coding, the incoming information is blocked into class of k bits, and every block is mapped into resulted block of n bits, where n>k.

In the canonical shape, n - k equality checks are processed among the information bits as per some arithmetical technique, and afterward added to the initial block. This is represented in Figure 3.8. This needs an expansion in transmission capacity by a factor of n/k. The corresponding of this factor is the effectiveness, or rate, of the code.

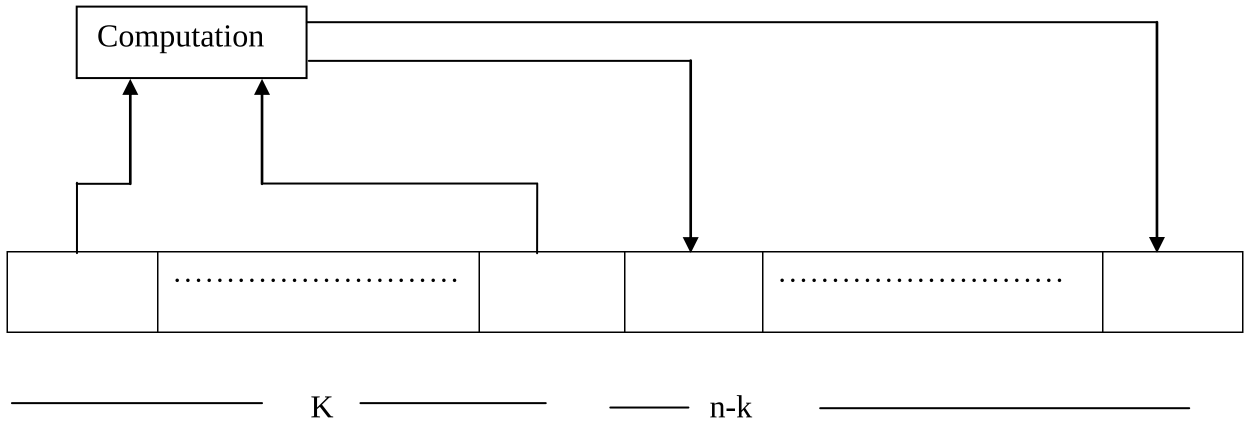


Fig.3.6. Construction of a Canonical Block Code

Just 2^k of the feasible 2^n output pieces are real code words. The code is picked as the minimal "Hamming distance", which is the quantity of bits in which code words contrast, is largest. The code is defined by the arrangement of numbers [n, k, d], where d is the minimal Hamming distance.

At the output, the n– bit piece is regained, perhaps with errors, by demodulation and framing. The decoder look for the legitimate code word that is nearest in Hamming separation to this got piece. Afterward the n – k test bits might be erased and the outcome result as a copy of the first information. On the off chance that d = 2t +1, at that point any arrangement of t or less blunders in the piece can be adjusted. In OFDM, if n concurs with the quantity of bits in an OFDM image, at that point every image is dealt with independently and no memory past an image is required for decoding.

The response enhancement accomplished by coding can see for the Gaussian channel. Here, not just the error possibility decreases, as well as the state of the curve alternated to one in which the blunder possibility diminishes strongly with little increment SNR ratio. For a moderately big block size, the strong reduction happens at a SNR ratio just a couple of dB greater than that which would output a perfect capability of a similar bit rate. The sharpness of the curve suggests that when a particular channel coding is utilized, minimal further advantage can be accomplished by source coding that decreases the impacts of errors.

A straightforward type of this coding that is broadly utilized for error recognition, not rectification, is the cyclic redundancy check. Here a settled number of check bits are added to a block of random length. Whenever, the recipient identifies any mistakes, a retransmission is asked. The encoding depends on a n-bit feedback shift register whose association design is basic polynomial. The acceptor applies a shift register with a similar association polynomial. This is demonstrated as follows.

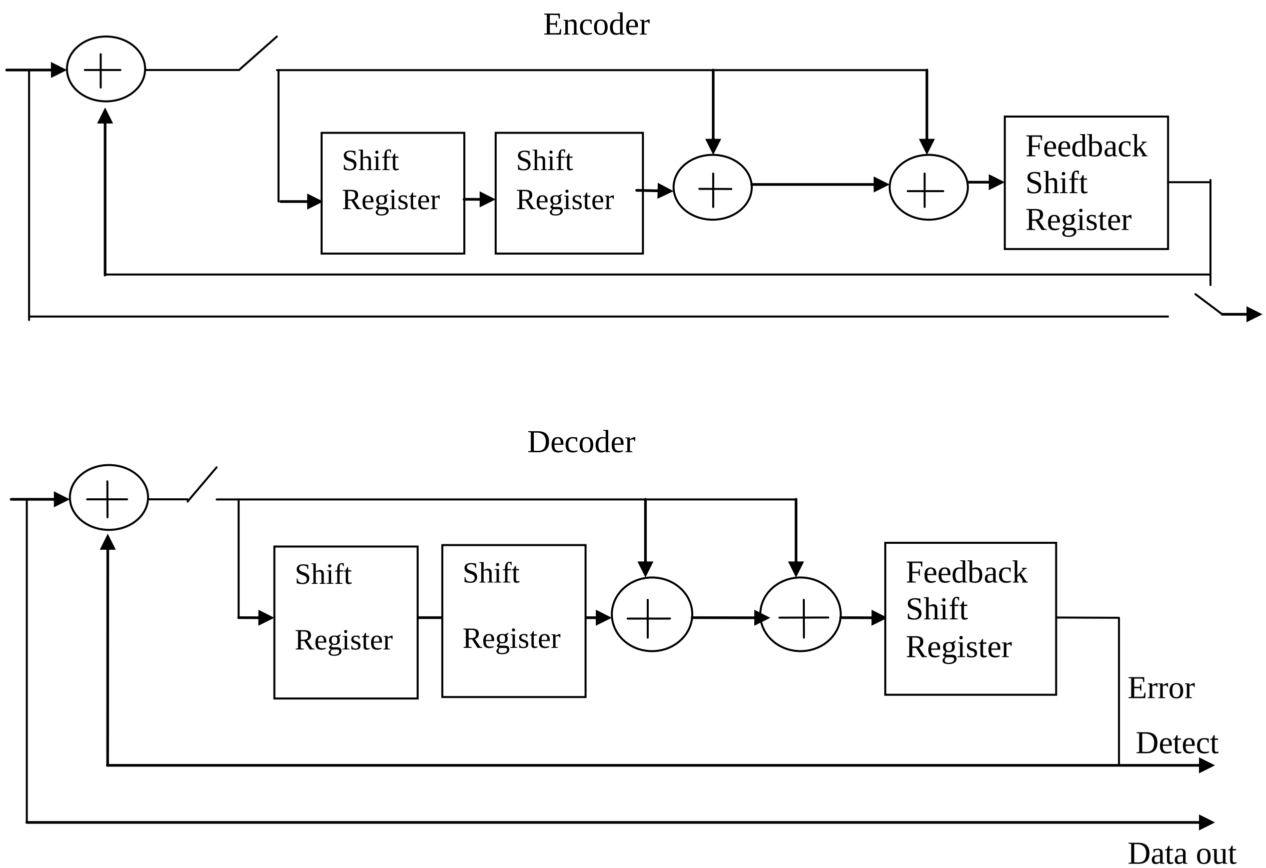


Fig.3.7. CRC Implementation

The services demonstrated are modulo-2 extension. At the encoder side, the shift register is started to given information, for example, all the ones. The incoming information is given to both to the channel and to the feedback shift register. After the information piece is finished, the ingredients of the shift register are moved out to the channel. At the recipient, the shift register is additionally instated. The got information is at the parallel output and given to the register. After finish of the uncoded bits, the ingredients of the register are analyzed. And every one of the zero state of these bits demonstrates that no blunders have happened. A CRC of length n can identify any mistake arrangement of length n or less. Some other blunder design is identified with possibility 1 – 2– n.

3.5.2 Convolutional Encoding

It is another important encoding technique in OFDM. It is little bit different from block coding which we have already discussed. In convolutional encoding the coding operates on streams of symbols instead of operating on symbols pattern as in block coding method. The input data given to the shift register of length m at the encoder side.

The memory of the code is the "constraint length" (m + 1), the quantity of yield images influenced by an info symbol. Every time a bit is studied within the register, severalmodulo-2 aggregates of the present and past bits are created. The decision of which bits are worked on is assigned as a polynomial P(z) with paired coefficients, n such modulo-2 totals are established and multiplexed to shape the yield of the "mother code". Since n bits are created for each info bit, the rate of the code is 1/n. In an elaboration not treated here, more than one piece at any given moment is processed in to a comparing number of shift registers.

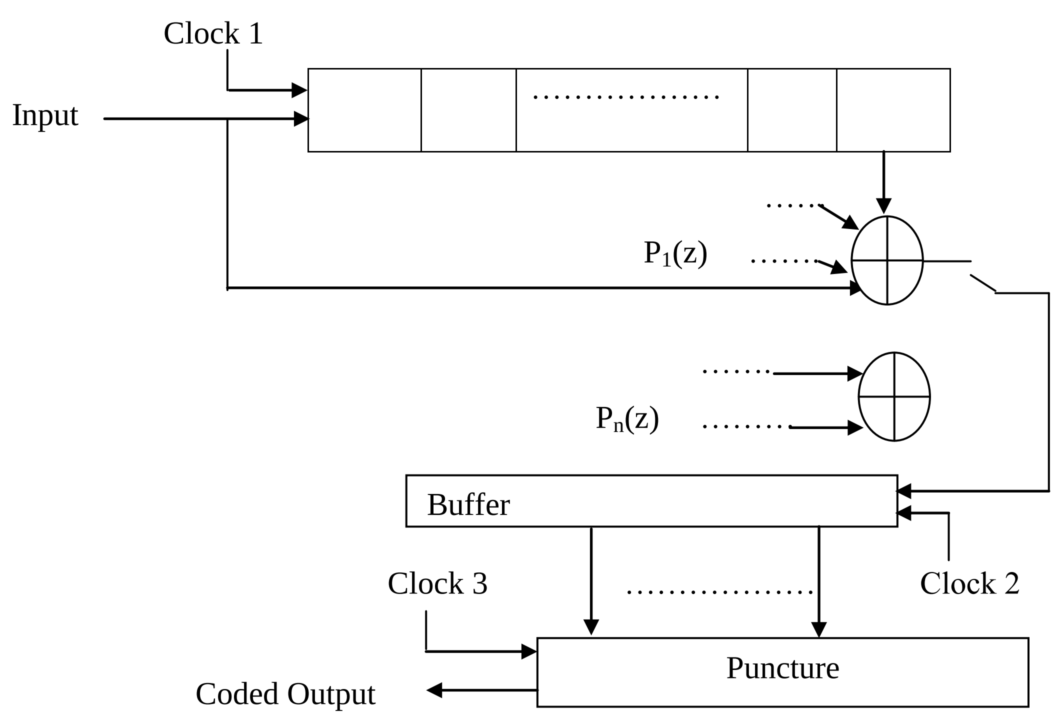


Fig.3.8. Generation of Convolutional Code

The data speed can be expanded by the way toward puncturing. This includes erasing a portion of the bits created by the mother code. The procedure of producing a convolutional code is appeared in 3.8. Moreover, interleaving might be connected to a convolutional code in a way like a block code.

A convolutional code can be depicted by a state chart. For a binary convolutional code, the quantity of states is s =2m, where m is the quantity of shift register steps in the transmitter. In the state graph appeared in Figure 3.9, the evolution from a present state to a next state are dictated by the present info bit, and every transformation develops a yield of n bits. The advantages of this coding are that it decoding is easy and it has very low complexity.

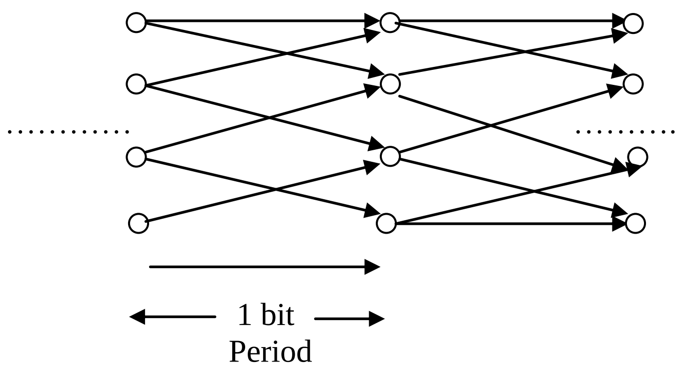


Fig.3.9. State Diagram of Convolutional Code

3.5.3 Concatenated Coding

It is a combination of block coding and convolutional encoding. It is very powerful technique of coding. The block coding is the outer coding that means first it applied at the transmitter and then the receiver. On the other hand, convolutional encoding is inner coding ant it is very efficient to mitigate the error possibility. It shown in the figure 3.10. Moreover, when convolutional code create an error then it looks like a very much burst. This happens when a viterbi – algorithm select a false pattern of bits. In this case outer code is efficient to make perfect the burst mistakes. For greatest efficiency the two codes ought to be interleaved, with various interleaving designs. Both interleaving sequence should represent both time and recurrence correlation.

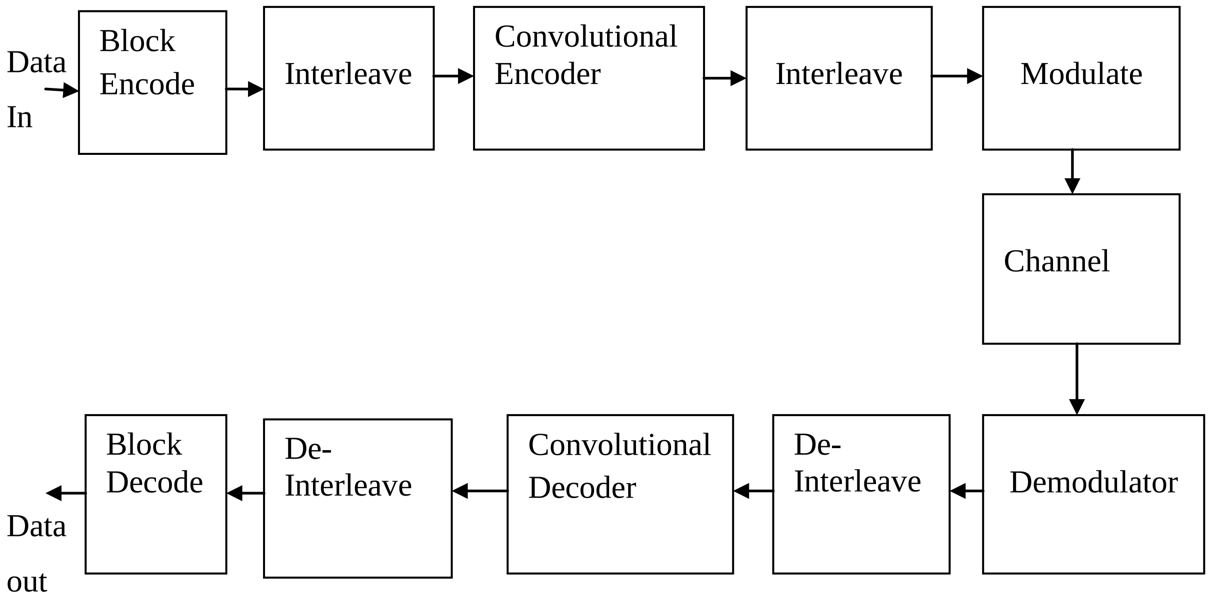


Fig.3.10. Concatenated Coding with Interleaving

3.5.4 Trellis Coding

To design a trellis code first step is to create an extended constellation and to divide it into subsets. The points between every subset are designed with a large distance from Euclidean distance, and correspond to bits without coded. The left, or coded bits, verify the alternative of subset. Simply definite sequences of subsets are allowed, those sequences being resolute by a basic convolutional code. Like in convolutional coding, the order is best explained by a position change graph or " trellis". To remain permitted series distant separated, the star grouping subsets are picked so those relating to fanning in and out of every position have most extreme separation division. We will show the strategy with a straightforward trellis code that uses a 16-point QAM constellation to hold 3 bits for each symbol. The method is too appropriate to phase modulation, where the quantity of stages is expanded. Appeared in Figure 3.11 is a division of the constellation into 4 subsets of 4 points all, where the marking of points means subset participation.

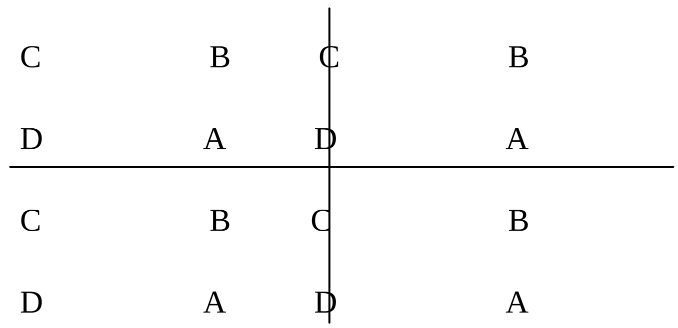


Fig.3.11. Expanded Constellation Partitioned for Trellis Coding

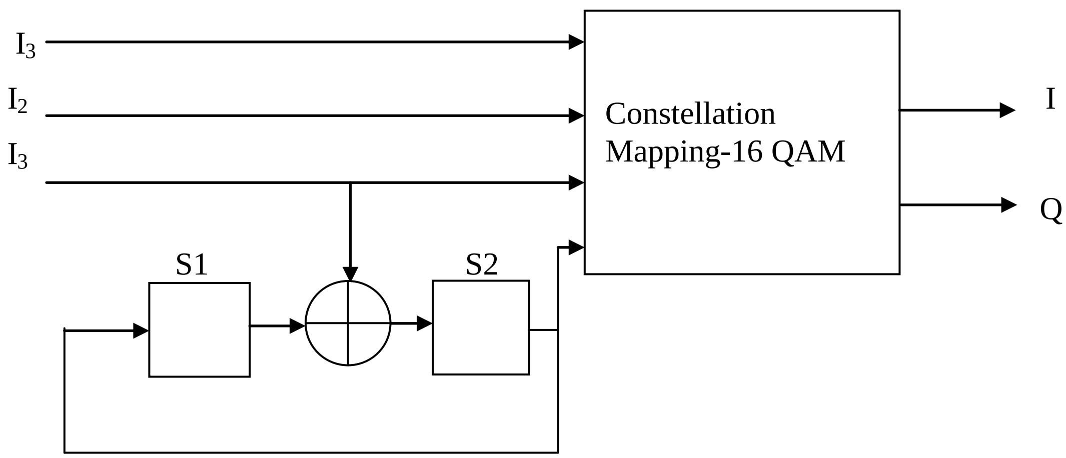


Fig.3.12. Implementation of a Trellis code

Figure 3.12 demonstrates the mapping of 3-bit input images into star grouping focuses. Two of the information bits, and, are uncoded and figure out which member from a subset is utilized. The third bit is feed to a rate-1/2 convolutional encoder whose 2-bit yield figures out which subset is utilized. Figure 3.16 is the state graph of the code. The states are named by the substance of the shift register in the convolutional encoder. The names of the changes show which subset is utilized when that progress happens.

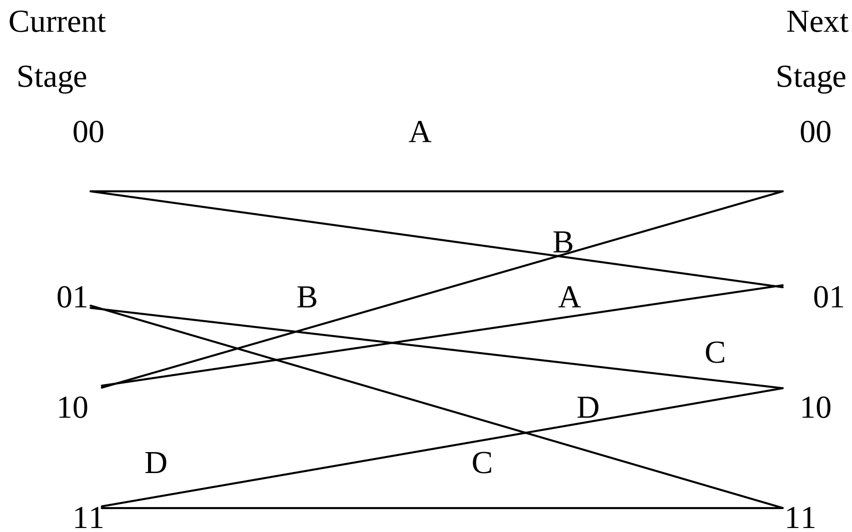


Fig.3.13. State diagram of the Trellis code

3.5.5 Turbo Coding in OFDM

Recently the turbo coding has been used in many communication system applications efficiently. It provides the less error rate, so that the performance of system increases. Turbo code consists of two or more concatenated or parallel codes.

The arrangement and complication of turbo encoder configuration is limited by other framework parameters. Here, we in brief analyses a portion of the basic issues which straightforwardly affect the code arrangement. Decoding Delay is basic for recipient design. As the decoding arrangement of turbo codes is iterative and incorporates an interleaving/de-interleaving block for every cycle, the larger postponement may meddle with general framework execution. For instance, communication frames ought to be handled inside a tight time span in many applications. Another significant framework configuration issue is needed coding gain. So the BER development of turbo coders is extraordinary, a framework creator ought to know about the results of low SNR framework usefulness. It is attractive to plan the framework for a low SNR condition expecting that an intense turbo code can meet the objective BER execution.

A usual turbo code incorporates parallel concatenated convolutional codes where the data bits are coded by at least two recursive deliberate convolutional codes each connected to permutations of the data arrangement as in Figure 3.14. Nonetheless, a similar iterative turbo interpreting standard can be connected to serially and half and half linked codes. The large error redress energy of turbo coders begins from irregular like coding accomplished by arbitrary interleaving in conjunction with concatenated coding and iterative decoding utilizing uncorrelated outward data.

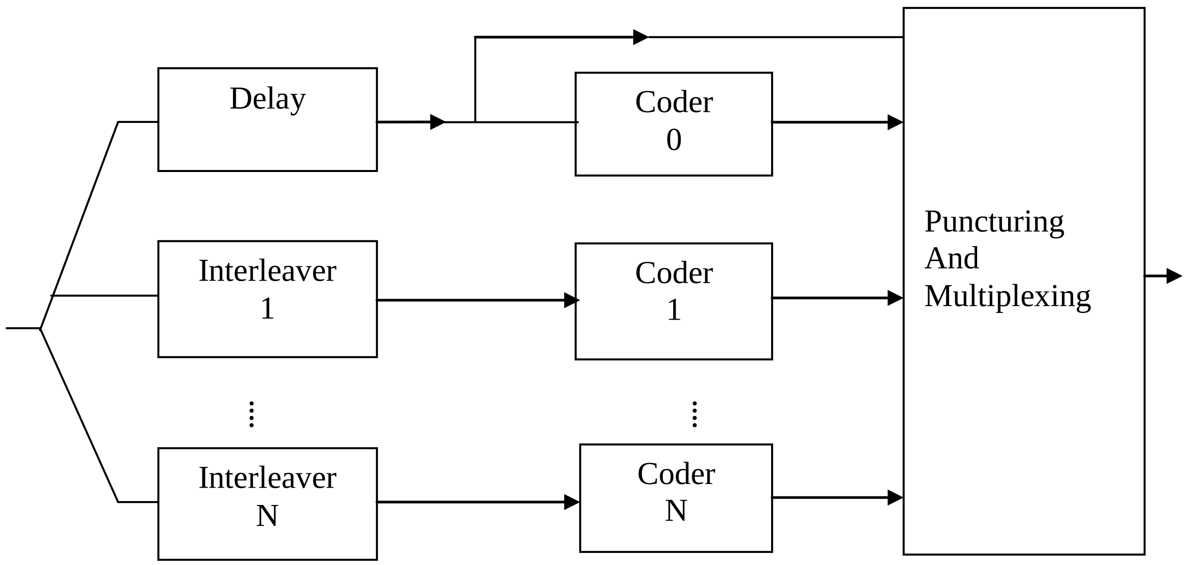


Fig.3.14. A typical turbo encoder

3.6 Advantages and Disadvantages of OFDM

- **Advantages**: OFDM used in many wireless systems due to its high data rate and immense advantages as:

1) It is very resistive in nature to frequency selective fading than the single carrier systems, because it allocates the entire channel to narrowband signals.
2) Interference does not affect the entire sub-channels. That means not all data get lost.
3) It makes efficient use of the available spectrum and it is less complex than FBMC.
4) Using channel coding and interleaving it is possible to regain symbols which has distorted due to the frequency selectivity of the channel and narrow band interference. Not all the data is lost.
5) An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler.

6) High flexibility while adopting MIMO techniques for OFDM

- **Disadvantages:**

1) OFDM suffers from high peak to average power ratio. That means an OFDM signal has a noise like variation in amplitude and has a big dynamic range, or peak to average power ratio.

2) Sensitive to carrier offset and drift: Another disadvantage of OFDM is that is sensitive to carrier frequency offset and drift. Single carrier systems are less sensitive.

3.6 Applications of OFDM

- **Digital Audio Broadcasting:** DAB is an advanced innovation offering significant focal points over the present FM radio, both to audience members and broadcasting. DAB's adaptability will likewise give a more extensive selection of projects, including many not accessible on FM. A solitary station may offer its audience members a decision of mono voice analyses on three or four donning occasions in the meantime, and afterward join the bitstreams to give superb sound to the show which takes after
- **Broadband power line communication:** Electrical cable Communications (PLC) is an innovation that exploits the current electrical foundation to convey correspondence systems. This paper proposes a design for the physical layer (PHY) of a PLC handset in view of Orthogonal Frequency Division Multiplexing (OFDM) and roused in the IEEE 1901 standard for Broadband PLC. The outlined framework is orchestrated on a Xilinx Spartan-6 FPGA gadget, and backings information rates up to 107 Mbps.
- **Wireless LAN:** It is a HIPERLAN 2 (European) introduced by ETSI High and scalable capability gives 54 Mbps information speed through a OFDM scheme**.**
- **LTE and LTE Advanced:** In Nov. 2004, 3GPP started a project to describe the long-term evolution (LTE) of Universal Mobile Telecommunications System (UMTS) cellular technology. OFDM was used in LTE for Higher performance, Improving spectral efficiency, Lowering costs, Improving services, Use of new spectrum opportunities, Improved quality of service.
- **High-definition Television (HDTV):** Commercial television station is first available by England. There live three technologies about the digital terrestrial television broadcasting system in European (COFDM), North America (8-VSB), and Japan (BST-OFDM). The European

introduces the COFDM modulation scheme into the system structure. American develop the model based on 8-level vestigial side-band (8- VSB) modulation scheme. Japan is keen to grow the band segmented transmission Orthogonal Frequency Division Multiplexing (BST-OFDM) system, which nature is based on COFDM modulation scheme.

3.7 Difference between OFDM and FBMC

FBMC is also a multicarrier scheme as OFDM, but there are some difference between FBMC and OFDM. FBMC has better spectral efficiency than OFDM. The main drawback of OFDM is use of CP (Cyclic Prefix) as shown in Fig.3.15 Cyclic prefix is basically a replica of conveyed symbol, due to this the throughput of transmission reduces. And using cyclic prefix the power wastage take place and it also requires the more bandwidth to transmit the signal.

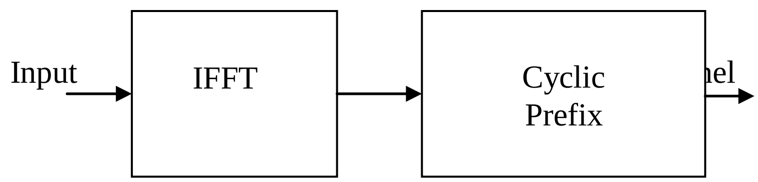


Fig.3.15. Basic OFDM Transmitter

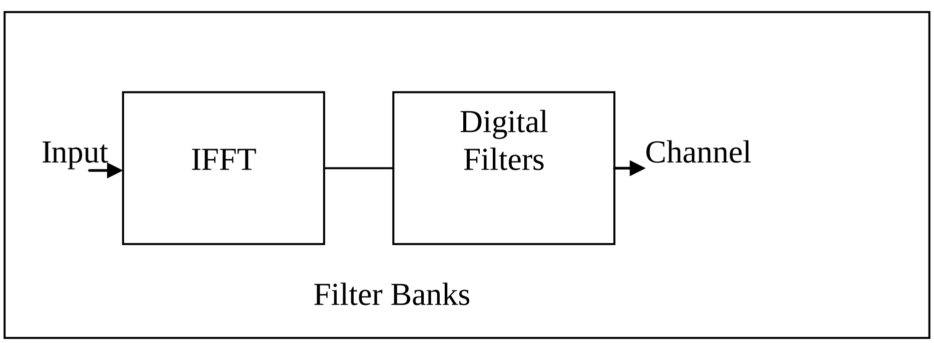


Fig.3.16. Basic FBMC Transmitter

Table.3.1: Comparison between OFDM and FBMC

Parameters	OFDM	FBMC
CP extension	Cyclic Prefix(CP) is needed, thus decreases the Bandwidth efficiency	CP not needed, So saves the Bandwidth
Side lobes	Large side lobes	Low side lobes
Doppler effect	extremely responsive to the carrier frequency offset	Fewer responsive, so raise the consumer mobility
MIMO Systems	Very much flexible when using MIMO schemes	Finite flexibility
Spectrum sensing	decreased spectrum responding activity by cause of spectral emission in OFDM signals	larger spectrum responding resolution

Filter bank modulation systems are more complicated than OFDM. This happens due to the swap of FFT/IFFT modules by the filter banks. Main contrast factor in these two schemes is quantity of multiplications (real) per symbol (complex). In OFDM realization, Split radix algorithm will have,

$$C_{FFT/IFFT} = M\,(\log(M) - 3) + 4 \qquad (3.7)$$

In FBMC, no. of real mltiplications per complex symbol is calculated as follows:

$$C_{SFB} = \log_2(M/2) - 3 + 4*K \quad (3.8)$$

$$C_{AFB} = 2\,(\log_2(M) - 3\,) + 4*K$$

Where, SFB is synthesis filter bank and AFB is analysis filter bank.

OFDM suffers from poor spectral selectivity compare to FMBC. The same is shown in the figure 3.17:

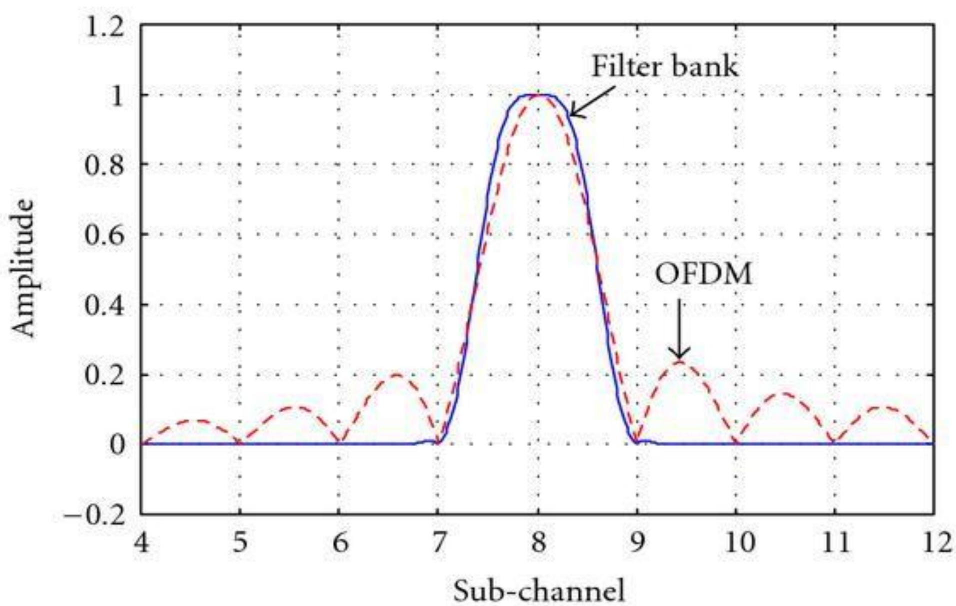


Fig.3.17. OFDM vs FBMC

3.8 FBMC System Model

The FBMC consists of identical filter banks at the transmission side and the receipt side, but this is not mandatory that the transmitter and receiver should use the identical filters. The FBMC transmitter consists of blocks as: OQAM (offset quadrature amplitude multiplexing), serial to parallel and parallel to serial data conversion block, frequency spreading and extended IFFT. Firstly we are giving the data bits to the mapping unit of FBMC as shown in fig. 3.20.

3.9.1 Introduction to FBMC

FBMC is derivative of OFDM. Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) have some drawbacks so that we use the filter bank based multi-carrier (FBMC), which provides the improved spectral and bandwidth efficiency. FBMC is the extension to the OFDM. As we know that the wireless devices connecting to internet increasing day by day with very fast rate. And this will further increase in future, so that to handle this situation new modulation techniques are needed. One of them is FBMC which provide the higher data rate than OFDM. This is the modulation technique which transmits the data by splitting it into various sub-channels and sends each sub-carrier over separate carrier signals.

3.9.2 FBMC Transmitter

The FBMC transmitter consists of blocks as: OQAM (offset quadrature amplitude multiplexing), serial to parallel and parallel to serial data conversion block, frequency spreading and extended IFFT. Firstly we are giving the data bits to the mapping unit of FBMC. The functioning of each block of FBMC transmitter is given as shown in fig.3.20:

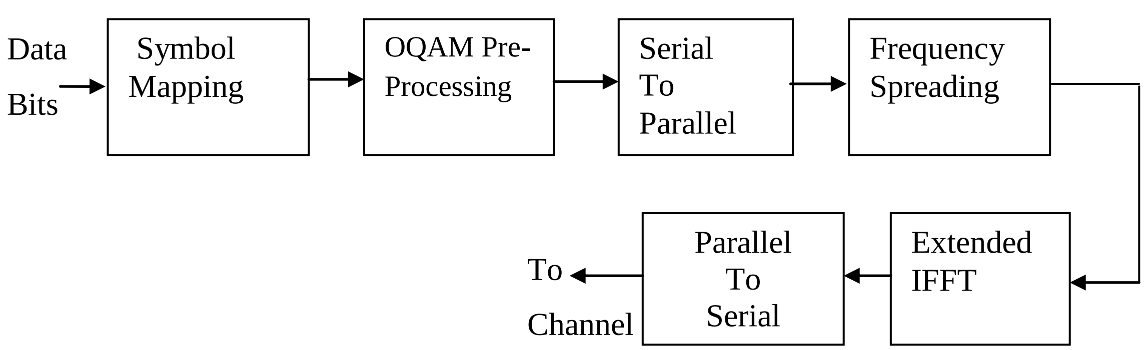


Fig.3.18. FBMC Transmitter

➢ Symbol mapping

In the FBMC transmitter the data bits are given to symbol mapping block. The mapping of the symbols takes place to reduce the overlapping between two or more symbols. To reduce the overlapping there is need to map the symbols perfectly. After that the OQAM is used to increase the data rate. In remote systems, the physical layer incorporates the remote medium, so the physical layer utilizes simple analog data to convey the bits. In other way, sinusoidal waveforms are utilized to transmit coded bits (1s) over the air. In a computerized systems, the sinusoidal waveforms are "discrete time" in nature in that a one sinusoidal waveform has a constant with an all pre characterized begin time and end time. Figure 3.19 shows such a game plan. Here, the coded bits to be transmitted are 1101, and the given plan is utilized to physically transmit the bits: if the information bit is a 1, then transmit a positive cosine waveform; if the information bit is a 0, then transmit a negative cosine waveform.

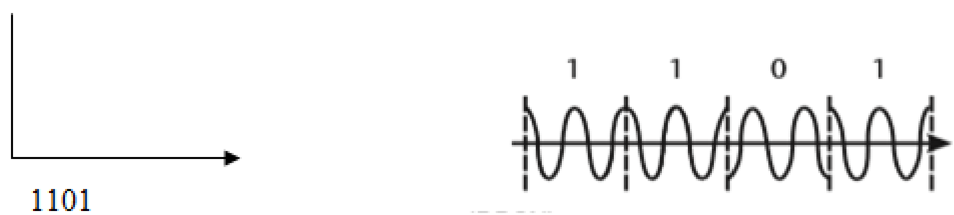


Fig.3.19. Simple Signaling Scheme

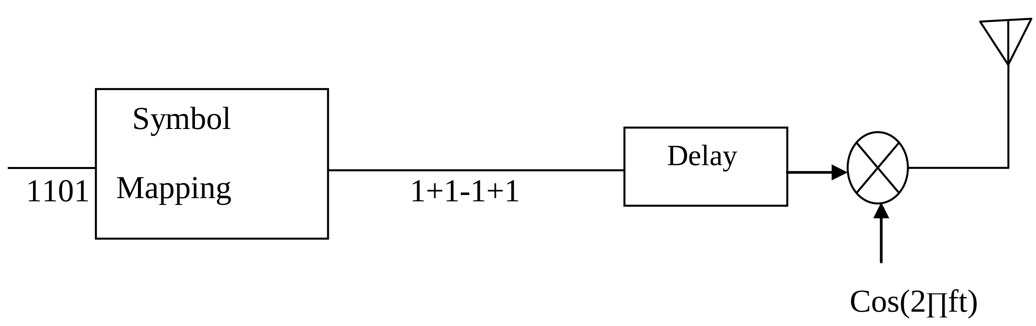


Fig.3.20. Simple Digital Transmitter

Figure 3.20 demonstrates the physical execution of this case. The baseband bit stream of 1101 goes into an image mapper, which maps each piece to a base-band image. The baseband image is +1 if the comparing bit is 1 and −1 if the relating bit is 0. The baseband image is then duplicated by a transporter cos(2πft). The subsequent pass band waveforms s(t) is then transmitted over the air. Figure 3.20 demonstrates the image group of stars for this plan. There are just two conceivable images {+1, −1}. Likewise, these conceivable images are genuine numbers, have just genuine segments, and lie on the genuine hub just; there are no fanciful parts in these images. Additionally take note of that these two images vary just in their stage, not in their greatness. The +1 image and the −1 image both have a magnitude of 1, yet they have a stage distinction of 180°. This plan is known as the parallel stage move keying (BPSK).

➢ OQAM Processing

In FBMC, any type of modulation can be utilized at whatever point the sub-channels are isolated. For instance, if just the sub-channels with even (odd) list are abused, there is no overlapping and QAM modulation scheme can be utilized. In any case, if high speed is needed, all the sub-channels must be misused and a particular modulation is expected to adapt to the recurrence space covering of the neighboring sub-channels. on the off chance that greatest information rate is the target, the neighboring sub-channels must be abused and the covering signs are isolated by the counterbalanced QAM method. In the plan, at time "n", the genuine contribution of sub- channel "i" is utilized, while it is the nonexistent contribution of sub-channels "i±1" which is encouraged by information. At time "n+1", it is the inverse. All the while, the image rate ends up plainly 2δf the time unit is 1/2δf. Truth be told, concerning QAM, a period balance of a large portion of the backwards of the sub-channel dividing is presented. OQAM (Offset quadrature amplitude multiplexing) have two different methods: first is the complex to real i.e. preprocessing and second is the real to complex conversion i.e. post processing.

In Complex to real conversion the real and imaginary parts of the complex valued symbol are separated to obtain the two symbols:

$$d_{k,2n} = \{Re[c_{k,n}];\ k\ \text{even}\} \quad (3.9)$$
$$= \{Im[c_{k,n}];\ k\ \text{odd}\}$$

And

$$d_{k,2n+1}=\{Im[c_{k,n}];\ k\ odd\} \quad (3.10)$$
$$=\{Re[c_{k,n}];\ k\ even\}$$

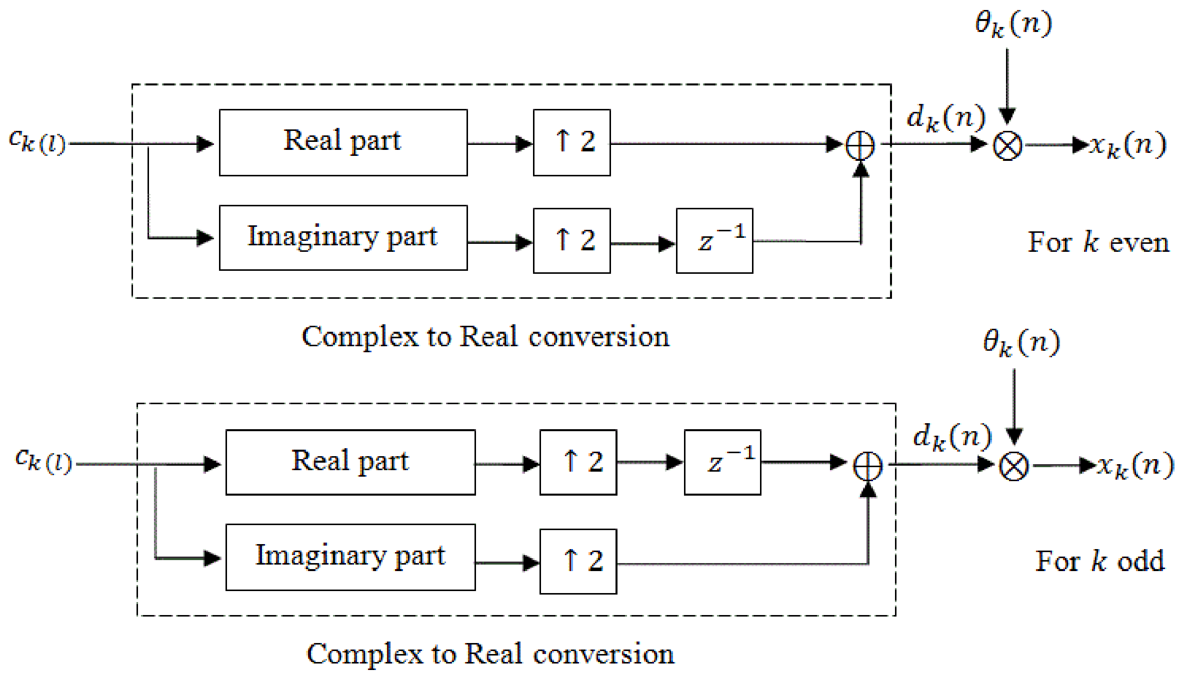


Fig.3.21. OQAM Pre-Processing

As shown in figure the complex valued signal divides into two real symbols one is real part and other is the imaginary part. This means that the complex-to-real conversion increases the sample rate by a factor of 2. To obtain this at the transmitter side the concept of interpolation is used, which can increase the sampling rate.

Similarly, in complex to real conversion two real valued symbols by multiplying by j, form a single complex valued symbol as:

$$C_{k,n}=\{d_{k,2n}+jd_{k,2n+1};\ k\ even\} \quad (3.11)$$
$$=\{d_{k,2n+1}+jd_{k,2n};\ k\ odd\}$$

The above equation 3.21 shows the pre- processing operation in which the two complex values have formed a single complex value. One is the real part and another is the imaginary part of complex value.

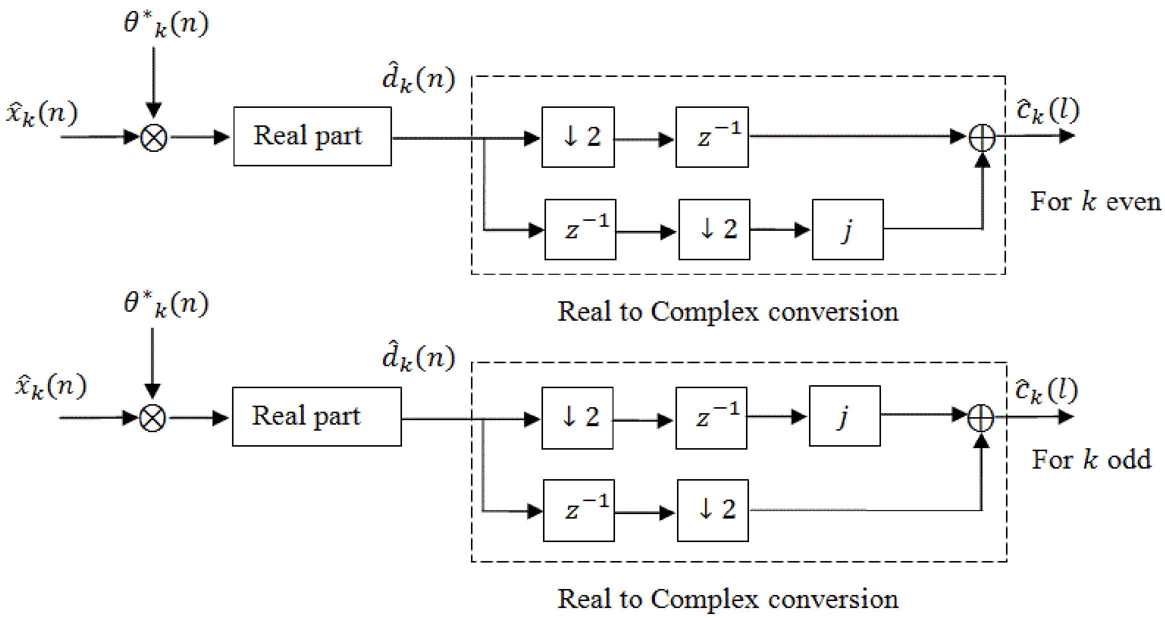


Fig.3.22. OQAM Post-Processing

In this the sample rate reduces by factor 2 to reduce the sampling rate at receiver. It basically use the concept of decimation to decrease the sampling rate at receiver side.

➢ Serial to Parallel (S/P) Conversion

Change of a flood of information components got in same time succession, i.e., each one in turn, into an information stream comprising of numerous quantities of information components transmitted at the same time. Appear differently in relation to parallel-to-serial change.

➢ Frequency Spreading

Spread range is a sort of remote trades in which the repeat of the transmitted banner is deliberately changed. This results in a significantly more unmistakable information exchange limit than the banner would have if its repeat were not changed. Frequency spreading allow us obtain more accurate equalization. So, large number of bits per symbol can be sent and the bandwidth of each subcarrier can be increased. Increasing the bandwidth of each subcarrier tends to greater bandwidth capability; lower complication; small senstive to carrier frequency offset (CFO); mitigated peak-to-average power ratio (PAPR).

➢ P/S, Overlap & Sum

Parallel to serial conversion is inverse of serial to parallel. In which each stream of data received in distinct time sequence, that's not at a one time, in to a data building of single data elements transmitted once time. It is called parallel to serial conversion. The overlap defined as when two signals are mixed with each other is called overlap, but in FBMC signals are not overlap with each other.

➢ Extended IFFT

A data symbols are applied to one input of the IFFT and it modulates one carrier. In a filter bank with interfering factor K, a data symbol modulates 2K-1 carriers. Therefore, the filter bank in the transmitter can be employed as : - an IFFT of length KM is utilized, to create all the mandatory carriers, - a particular data symbol di (mM), after multiplying by the filter frequency parameters, is given to the 2K-1 inputs of the IFFT. In real, the data symbol is stretched over various IFFT inputs and the procedure can be known as "weighted frequency spreading". For every input, the output of the IFFT is a combination of KM samples and, the symbol rate is 1/M, K consecutive IFFT outputs overlap in the time domain. Therefore, the filter bank output is given by an overlap and sum operation.

3.9.3 FBMC Receiver

Filter Bank Multicarrier receiver work the opposite from transmitter to obtain the actual information back. It contains the FFT, symbol de – mapper and frequency de-spreading etc blocks.

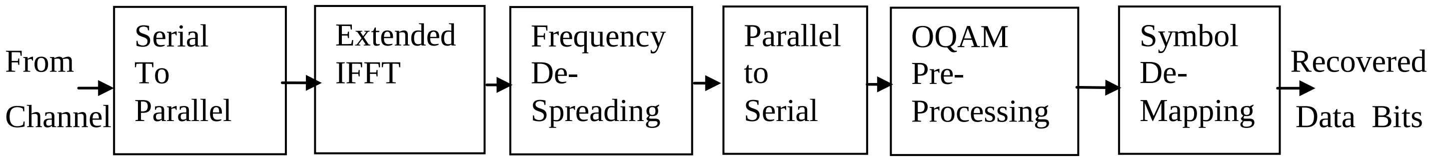


Fig.3.23. FBMC Receiver

For the better performance of the receiver the transmitter should align in time domain properly with transmitter. Now the channel has multipath propagation, which is due to impulse response of channel. So that the multicarrier overlap with each other, and it is not possible to demodulate the symbol with FFT at the receiver. Because inter-symbol interference has been developed and due to that orthogonality has been lost. So we have two options for this, one is the increase the symbol time and guard time, called OFDM. Another option is the add some processing to FFT and keep time and guard interval as they are previously. This is called FBMC, because the additional processing and FFT combined together which construct the filter bank

➢ Frequency de-spreading

It acts inverse of frequency spreading. It is used to regain the transmitted signal at the receiver side. Received baseband waveform is the combination of the transmitted waveform and noise in the channel.

➢ Symbol De-mapping

The de-mapper modulation type matches the mapper's modulation types, where the original transmitted signal should be recovered. It perform the operation opposite from the mapper at the receiver side. At the receiver end data bits are recovered.

3.9 Polyphase Filters Representation in FBMC

The transmit filter P is a limited impulse response filter holding L_p= KM factors, and its z-transform is as:

$$P(z)=\sum_{m=0}^{L_p-1} p[m]\ z^{-1} \tag{3.11}$$

Here, K is the overlapping factor. P(z) can be break down into M fundamental filters. Hence it creates a polyphase network:

$$P(z)=\sum_{m=0}^{Lp-1} p[m]^{z-1} = \sum_{n=0}^{M-1}\ \sum_{k=0}^{K-1} p[kM+n]z^{(-kM+m)}$$

$$=\sum_{m=0}^{M-1} \Big[\sum_{k=0}^{K-1} p[kM+m]z^{-km}\Big]z^{-m} \tag{3.12}$$

$$=\sum_{m=0}^{M-1} A_m(z^M)z^{-m}$$

Where,

$A_m(z^M)=\sum_{k=0}^{K-1} p[kM+m]z^{-kM}$ are the polyphase elements of P(z)

Now, let the $A_i(z)$ derived from the A(z) with the frequency shift of i/M:

$$A(z)=\sum_{m=0}^{Lp-1} p[m]\ e^{(j2\prod/M)im}z^{-m} \tag{3.13}$$

Using polyphase representation, $A_i(z)$ is written as:

$$A_i(z) = \sum_{m=0}^{M-1} \sum_{k=0}^{K-1} p[kM+m]\, e^{(j2\Pi/M)i(kM+m)} z^{-(kM+m)}$$

$$= \sum_{m=0}^{M-1} e^{(j2\Pi/M)mi} A_m(z^M) z^{-m} \qquad (3.14)$$

A uniform filter bank is achieved by moving the output of *A(z)* on the frequency axis. It is hence derived from *A*(*z*), that is, thus, known as the prototype filter of the filter bank.

If whole the filters are derived from the prototype filter by frequency move multiples in 1/*M*, then the filter bank has these expression:

$$\begin{bmatrix} P_0(z) \\ P_0(z) \\ \vdots \\ P_{M-1}(z) \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & w^{-1} & \cdots & w^{-(M-1)} \\ \vdots & \vdots & & \vdots \\ 1 & w^{-(M-1)} & \cdots & w^{-(M-1)2} \end{bmatrix}}_{IFFT} \begin{bmatrix} A_0(z^M) \\ Z^{-1} A_1(z^M) \\ \vdots \\ Z^{-(M-1)} A_M(z^M) \end{bmatrix} \qquad (3.15)$$

Where $w=e^{j(2\Pi/M)}$, and the *N*-order inverse Fourier transform matrix is expressed by *IFFT*.

3.10.1 Synthesis and Analysis Filter Banks

Filter Bank Multicarrier system used the transmultiplexer (TMUX) arrangement, with the SFB (Synthesis Filter Bank) at transmitter side and AFB (Analysis Filter Bank) at the receiver side.

Figure 3.24 demonstrates the filter banks in this design as major piece of an entire FBMC/OQAM transmission/receiver framework. This Filter Banks scheme expands on uniform modulated filter banks, in which a prototype filter p[m] of length L_p is moved in recurrence to create sub bands which wrap the entire system radio band. The yield of such a synthesis filter bank can be defined by

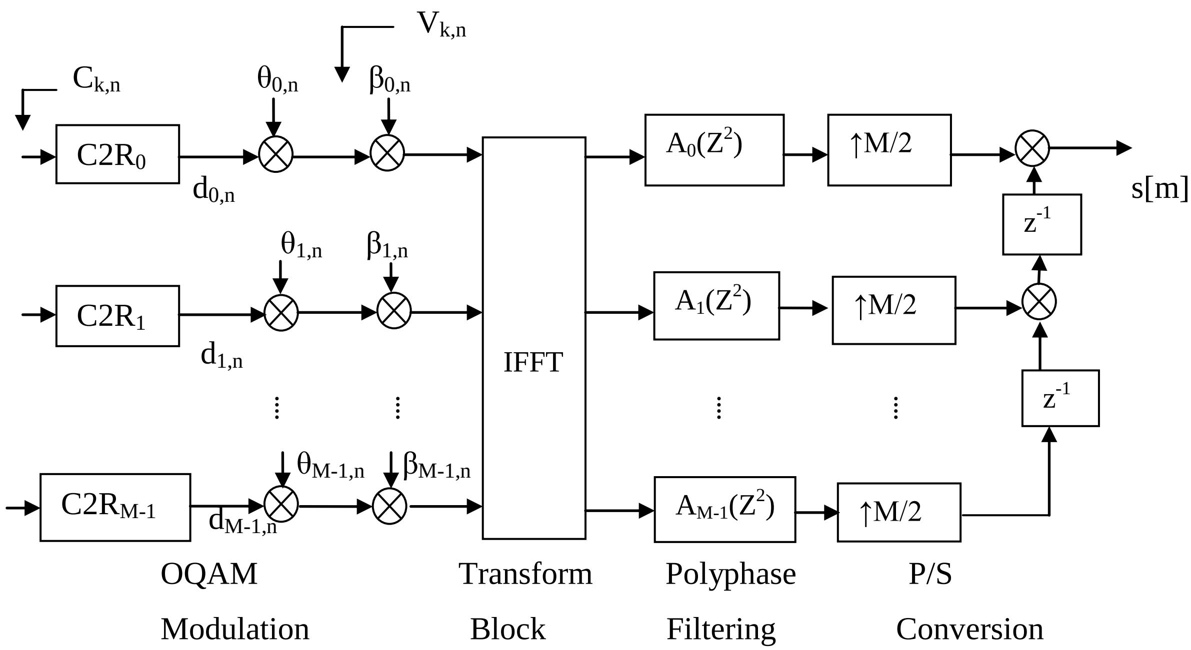


Fig.3.24. Synthesis Filter Banks

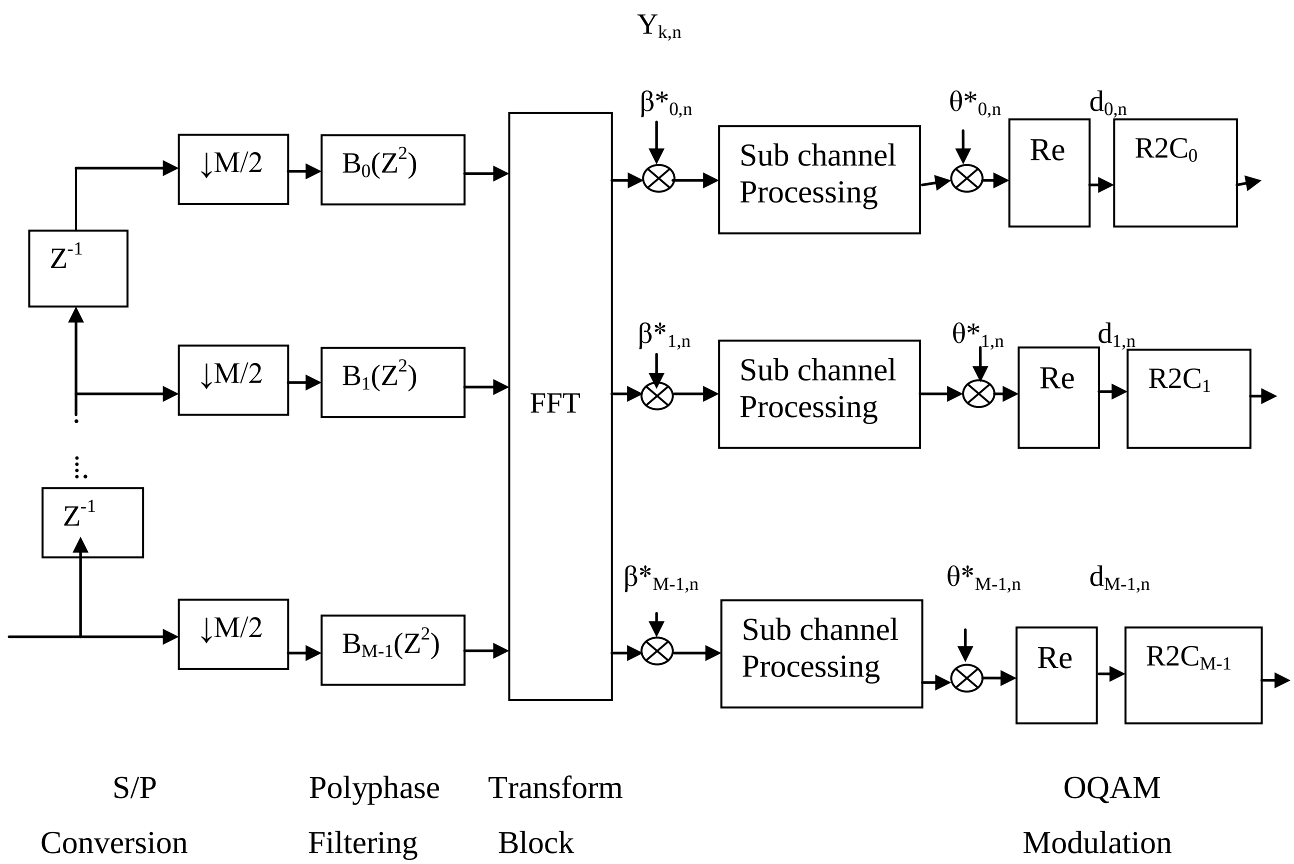


Fig.3.25. Analysis Filter Banks

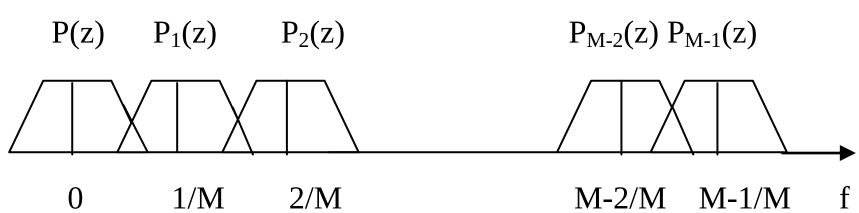


Fig.3.26. Frequency Response of Filter Banks

$$S[m]=\sum_{k=0}^{M-1}\sum_{n=-\infty}^{\infty} d_{k,n}\,\theta_{k,n}\,p[m-nM/2]e\ j^{(2\prod/M)k(m-n(M/2)-((Lp-1)/2))}, \tag{3.16}$$

Where,

$$\theta_{k,n=}\ e^{j(\prod/2)(k+n)} = j^{k+n} \tag{3.17}$$

m is the model index at the result of the Synthesis filter bank (at large data rate),M is the quantity of sub channels in the filter bank, and $d_{k,n}$ are the real esteemed information images in sub channel k, transmitted at a rate. The flagging duration is characterized as T=1/Δf, where Δf is the subcarrier distance. The group of symbols $d_{k,n}$ and $d_{k,n+1}$ can be translated as holding the in-phase and quadrature data of a complex-esteemed symbol transferred at rate 1/T. Hence, the filter bank showed in Figure 3.26 is fundamentally inspected. The "$C2R_k$"-blocks show the change into real-valued information from the real and imaginary section of the complex-esteemed info symbols and can be calculated as presenting up sampling by 2. "$R2C_k$" brings the reverse operation after the Analysis filter Bank in the recipient, successfully down sampling the signal by 2. In FBMC/OQAM, $c_{k,n}$ related to a QAM letter real and imaginary portions are interleaved with a comparative time offset of T/2(thus offset QAM) and $C2R_k$ accomplish the following mapping:

$$d_{k,2n}=\begin{cases}\mathrm{Re}\left[c_{k,n}\right], & k\ \text{even}\\ \mathrm{Im}\left[c_{k,n}\right], & k\ \text{odd},\end{cases} \tag{3.18}$$

And

$$d_{k,2n+1}=\begin{cases}\mathrm{Im}\left[c_{k,n}\right], & k\ \text{even}\\ \mathrm{Re}\left[c_{k,n}\right], & k\ \text{odd}.\end{cases} \tag{3.19}$$

Always keep in mind that the indications of the sequences in (3.18)-(3.19) could be picked subjectively, however the model of real and imaginary symbols after multiplication by $\theta_{k,n}$ needs to follow the above definitions to keep up orthogonality.

This kind of filter bank sets can be effectively designed utilizing FFT and IFFT of size M supported by polyphase filtering structures. The diverse parts of the polyphase SFB structure of can be better recognized by taking note of that $a_k[m]= p[m+kM]$ and rewriting (3.7) as

$$S[m]=\sum_{k=0}^{M-1}\sum_{n=-\infty}^{\infty} d_{k,n}\,\theta_{k,n}\,\beta_{k,n}\,p[m-nM/2]\,e^{j(2\Pi/M)km}, \tag{3.20}$$

Where,

$$\beta_{k,n}= (-1)^{kn}\,e^{-j(2\Pi k/M)((Lp-1)/2)} \tag{3.21}$$

Here, the factor $(-1)^{kn}$ focuses the low-rate resulted signal of every sub channel k of the analysis filter bank approximately DC.

The synthesis and analysis banks in Figure3.26, between the OQAM modulation and the sub channel handling parts, separately, can likewise be understood from the established FB introduction: each sub channel k with its own particular up/down sampling and sub channel filters. The synthesis/analysis sub channel filters are, individually, gotten from the prototype filter p[m] as

$$g_k[m]= p[m]\,e^{-j(2\Pi/M)k(m-(Lp-1)/2)}, \tag{3.22}$$

$$f_k[m]= g^*_k[Lp-1-m],$$

Where m=0,1,-----,L_p-1 and (.)* indicates complex conjugation

Further, the length L_p of the prototype filter p[m] relies upon the amount of the filter bank and the integer number overlapping factor k as L_p=kM, where the factor k shows the quantity of FBMC/OQAM image waveforms that overlap in time. In different lengths of the prototype filter, near to $L_{p=}$ kM, are investigated. Larger values for k permit more opportunity in outlining the prototype filter, for instance to get high stop band attenuation. Further it raises the time needed for the processing of every symbol. The prototype filter p[m] can be outlined such that the filter bank pair yields perfect reconstruction (PR) of the transmitted information if there should arise an occurrence of a perfect channel, that is, the gotten information grouping $d_{k,n}$ approaches the transmitted information $d_{k,n}$, if there is no extra preparing included. Techniques to outline PR prototype filters can be found. In any case, in practical communication frameworks, the channel will dependably establish some disturbance with the flag. Accordingly, the outline limitations can be to some degree comfortable and the prototype can be improved to get nearly PR (NPR). The trade off, when contrasting and PR designs, is that for prototype filters of a similar length, NPR plans can get larger stop band attenuations, or with constant stop band attenuations, the NPR prototype filter can be lesser. This occurs at the cost of permitting some minor intersymbol (ISI) and intercarrier (ICI) interference from the filter bank, well under the noise level of the correspondence channel.

3.10.2 FBMC Merits and Demerits

- **Merits:**
  1) Provide spectrum efficient and more selective system
  2) CCP(Cyclic Prefix) is not needed
  3) Provide robust narrowband jammers
- **Demerits:**
  1) The growth of MIMO based FBMC is very limited and is not minor.
  2) To plan larger bandwidth and greater dynamic range structure will have more challenges in achieving RF performance
  3) Very much complex as compared to OFDM. It introduces overhead in overlapping symbols in the filter bank (in time domain)

3.10.3 Applications of FBMC

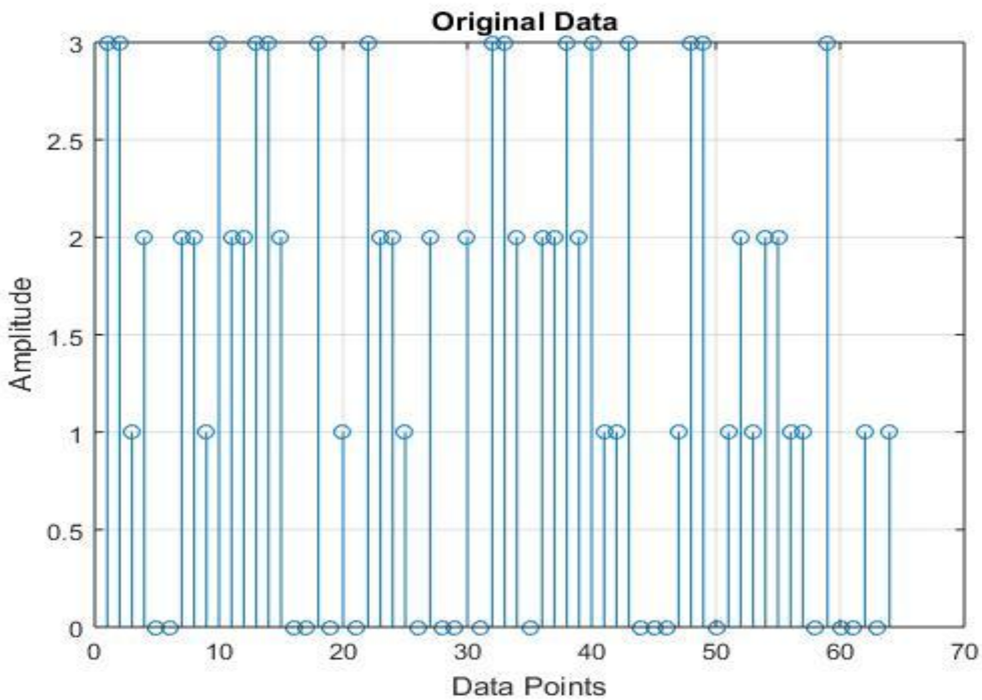
I. Cognitive Radio Communications

II. Multiple Access Networks

III. Access to Television White Space (TVWS)
IV. Power Line Communication
V. MIMO Communication

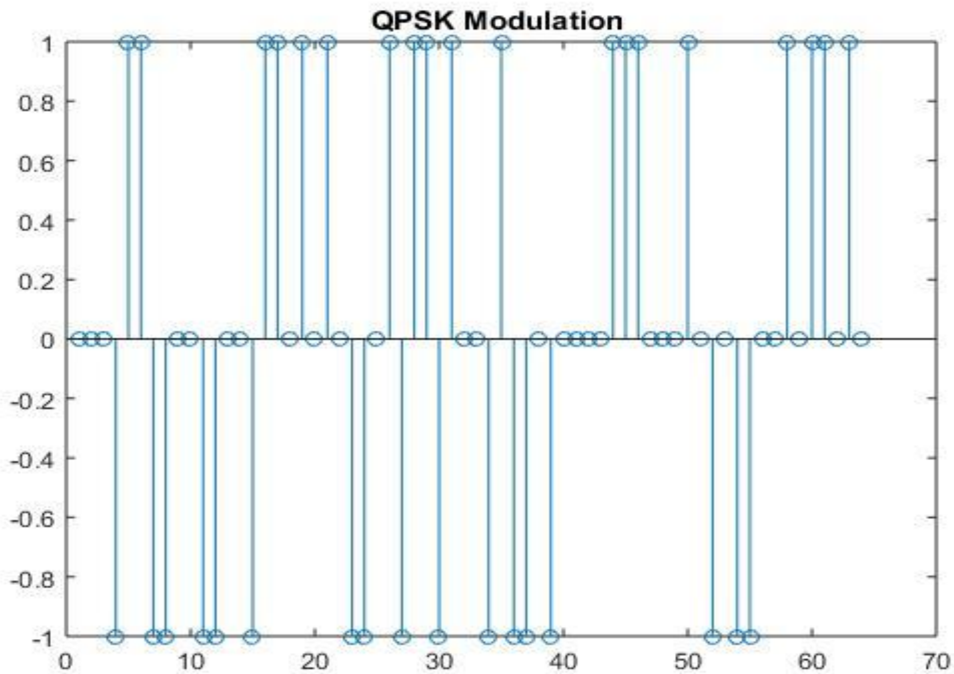
OFDM is one of the most important candidate waveform for 5G. Figures given below are showing the performance of OFDM transmitter and receiver in detail. OFDM transmitter consists of binary data source, symbol mapping, IFFT, Addition of CP. And then this data transmitted through the AWGN channel. Fig 4.1(a) shows the input binary bits which is transmitted from the source. These random data bits are 64 bits of length

4.1 OFDM Simulation and SNR vs BER in OFDM

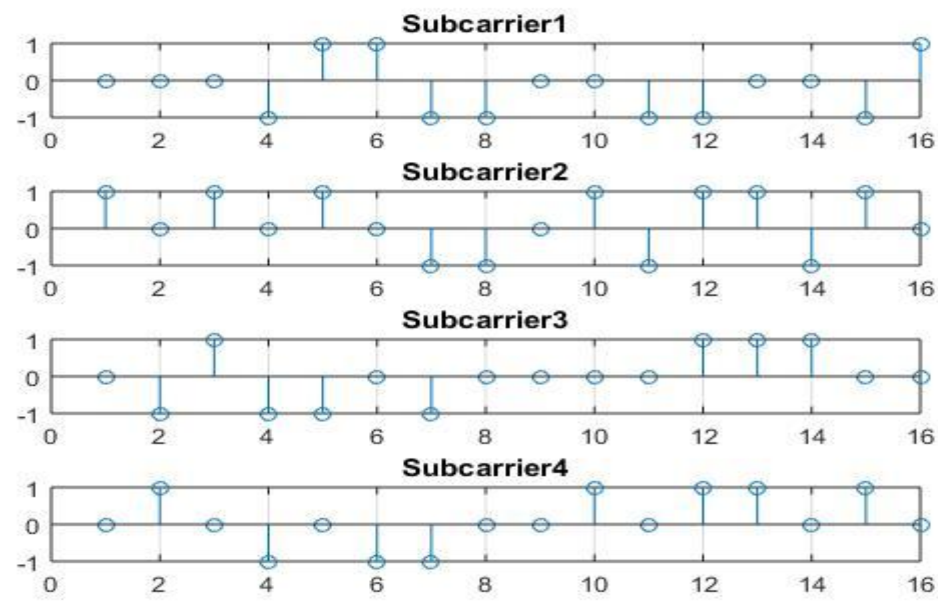


(a) Input Binary Data

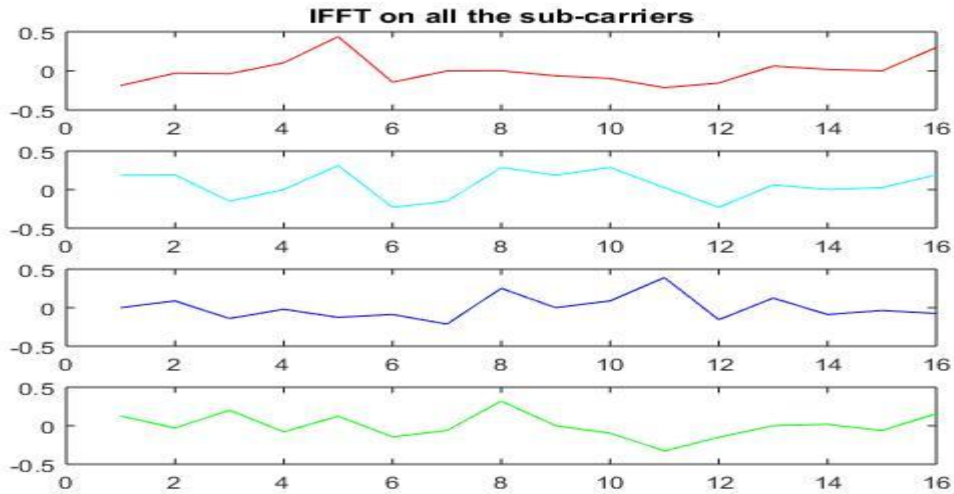
.



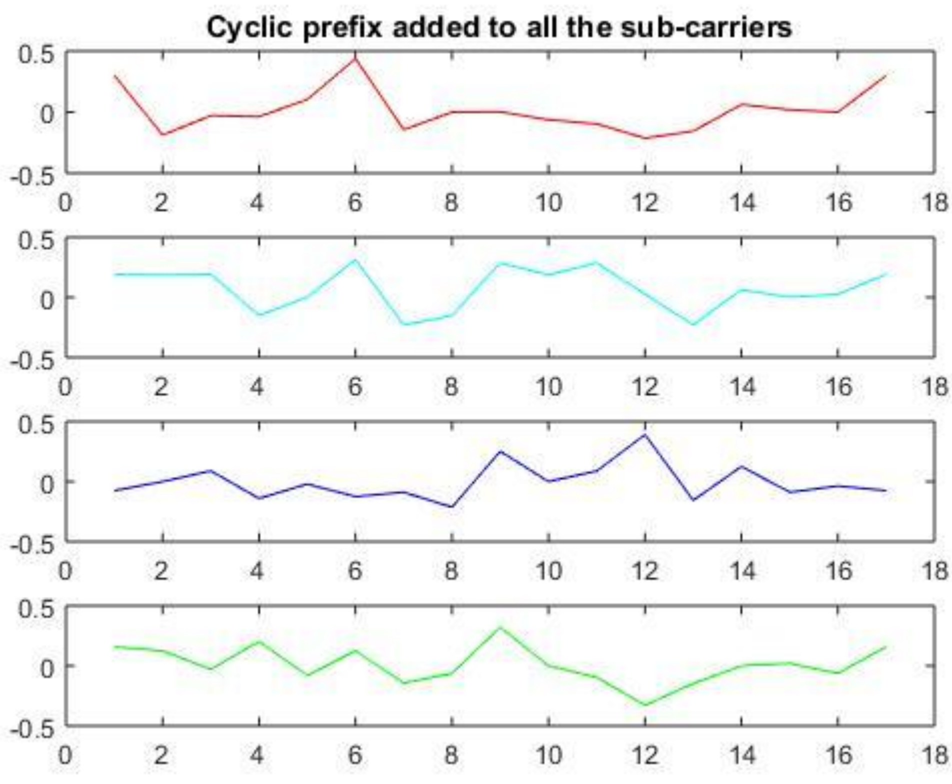
(b) OFDM –QPSK Modulation Plot



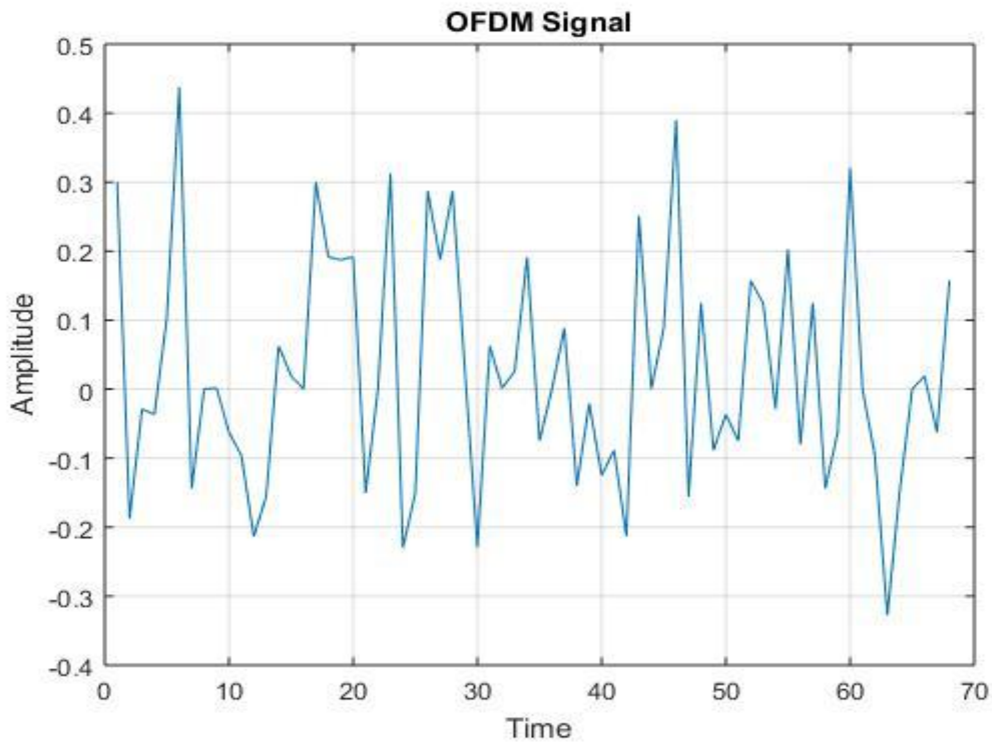
(c) Plot of OFDM Subcarriers



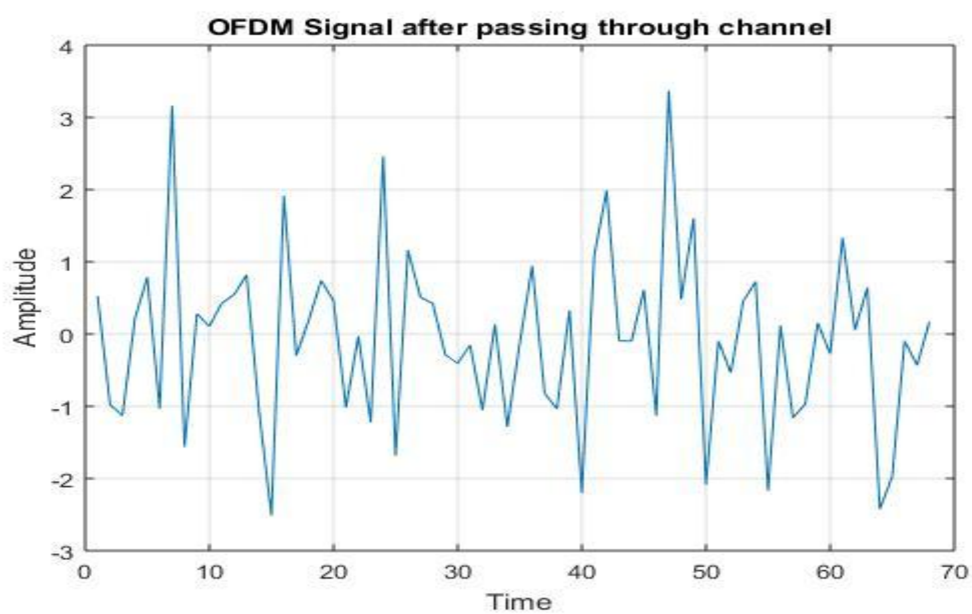
(d) IFFT of All Subcarriers



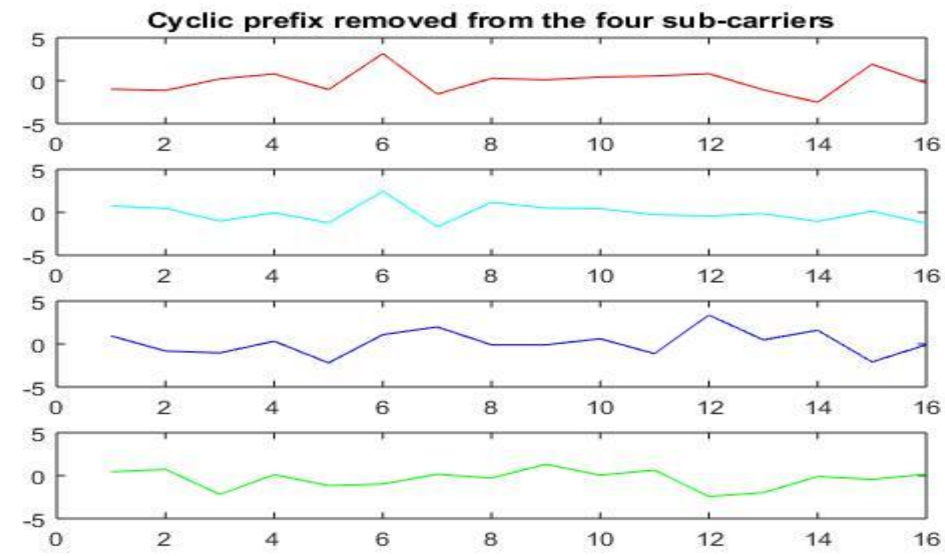
(e) CP Insertion to All Subcarriers



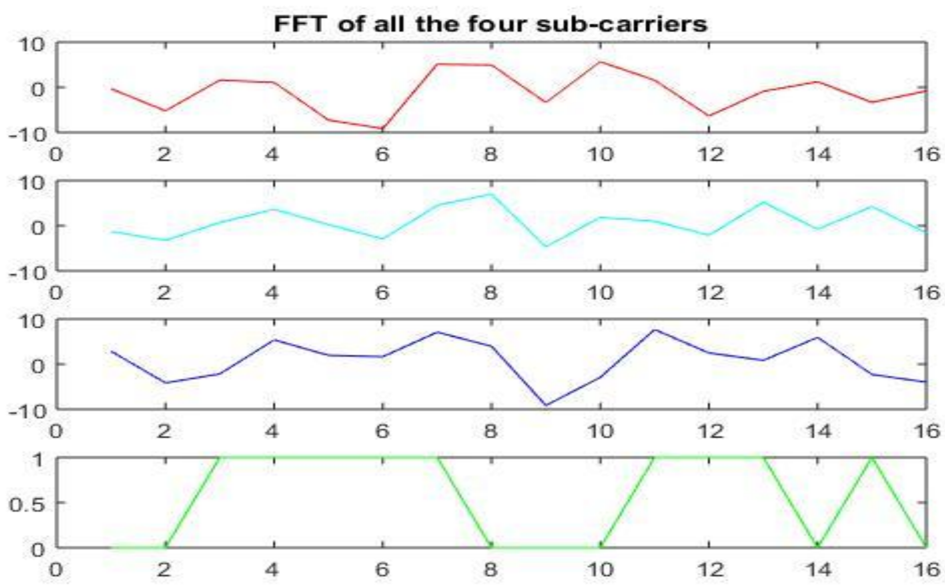
(f) OFDM Transmitted Signal



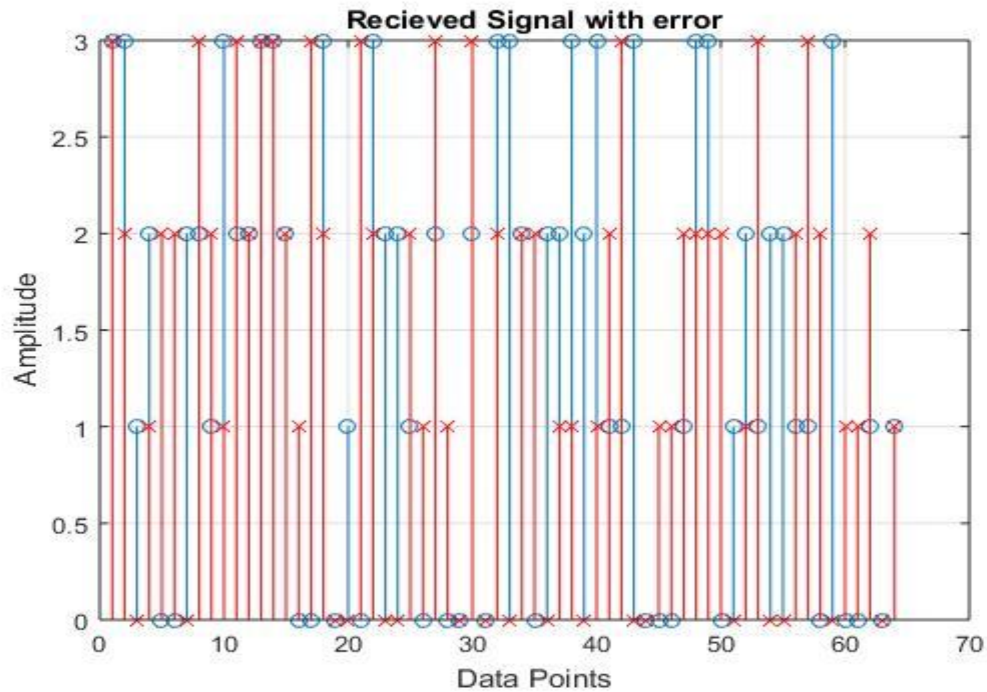
(g) OFDM Signal with AWGN Channel



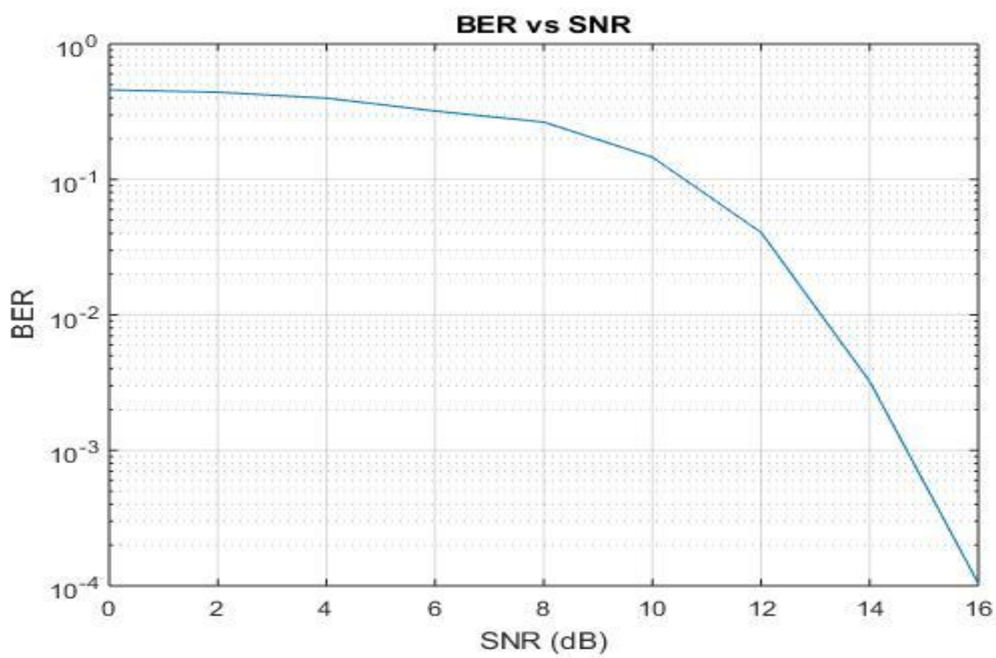
(h) CP Removal to All Subcarriers



(i) FFT of all Subcarriers



(j) OFDM Received Signal

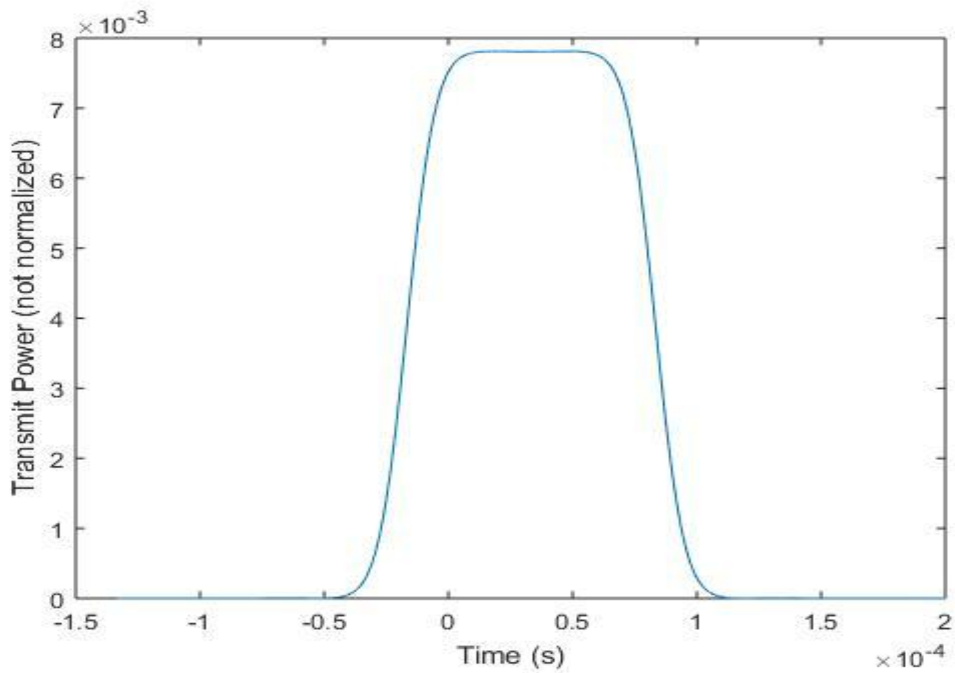


(k) BER vs SNR

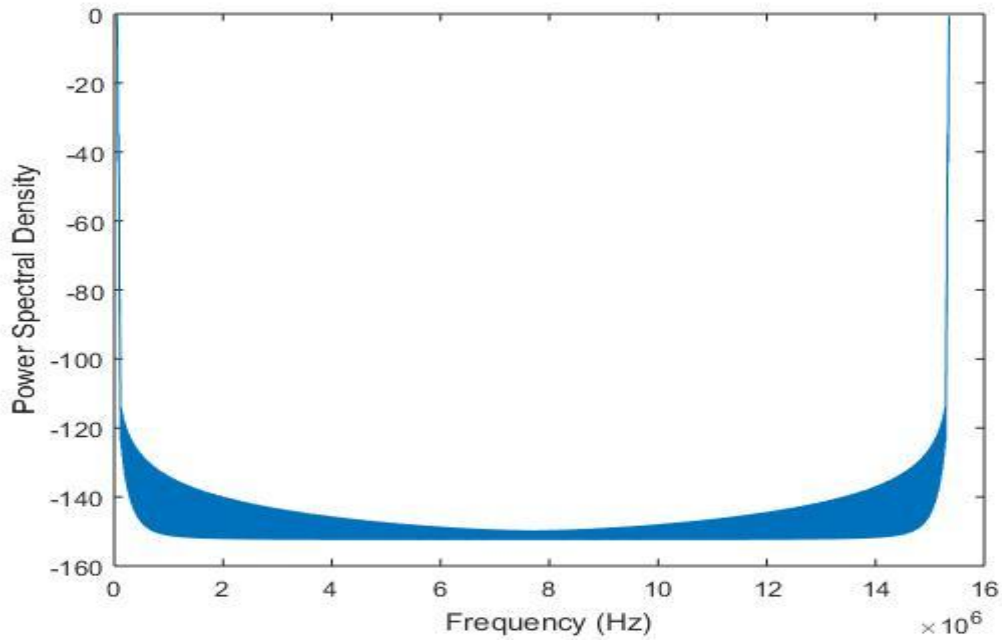
Fig.4.1 OFDM Transmitter and Receiver Implementation and BER vs SNR Plot

BER vs SNR plot for OFDM and the transmitter and receiver working has been shown in Fig.4.1 (a) - (k). Here the graphs depicted the performance of the system at each block of the OFDM transmitter and receiver. The graphs (a) – (f) are showing the transmitter for OFDM and the graph (g) is the AWGN channel performance when OFDM signal passes through it. Plots (h) – (j) depicting the receiver side. At last the BER vs SNR plot represent that when the SNR increases the BER decreases.

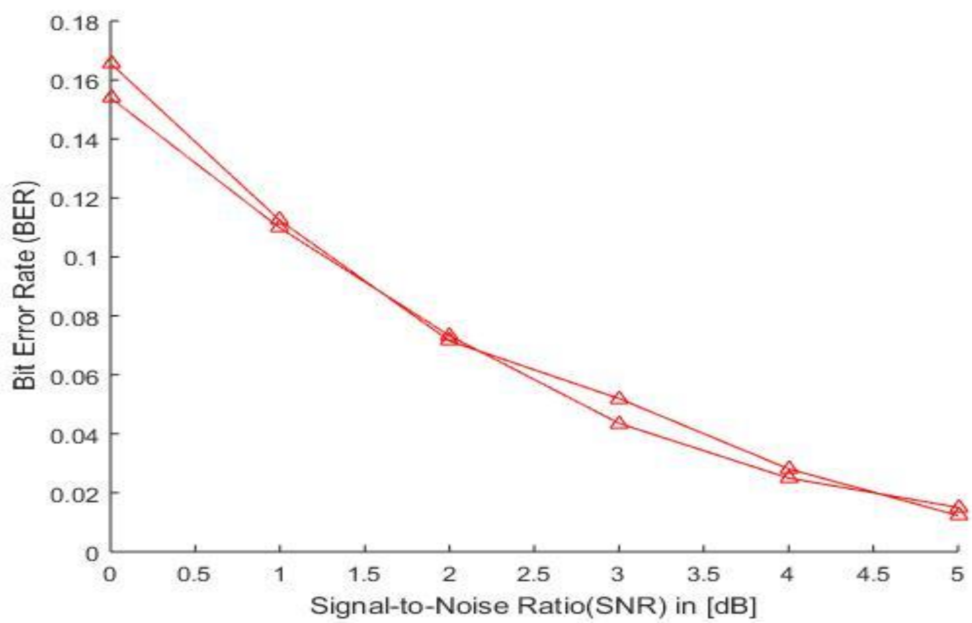
4.2FBMC Simulation and BER vs SNR in FBMC



(a) Transmission Power



(b) PSD



(c) SNR vs BER

FBMC performance of transmitter and receiver is present in the PSD graph and the BER vs SNR graph as depicted in figure 4.1.(a) (c). In FBMC arrangement filtering is given on per sub carrier basis which gives good sub carrier distinction and it is not necessary to add cyclic prefix as OFDM and hence the FBMC is having more spectral efficiency than that of OFDM. FBMC gives good sub carrier distinction because it filters the signal on per sub carrier basis but higher FFT size and the filtering scheme used in signal creation makes the system much more complex than that of OFDM. SNR increases with the BER reduction.

Chapter-5: Conclusion and Future Scope

5.1 Conclusion

Here, we intended the FBMC transmitter and recipient side and more it is projected in 5G wireless communication arrangement. At the transmitter side we have used the OQAM processing and the synthesis filter bank. In recipient side we have used the polyphase structure and the OQAM post processing. To mitigate the computational complication we have utilized multiple stage filter banks. Our concentration is on scheming of FBMC and accomplishment as the suitable waveform for the 5G communication arrangement. In simulation outcome we can obviously find that the limitations of OFDM are recovered by the filter bank multicarrier. FBMC perform filtering on a per-subcarrier basis to give out of band spectrum characteristics. The baseband filtering is completed using either a poly phase network or an extended IFFT. Filtering can use distinct interfering factors to give changeable levels of out-of-band rejection. So, QAM-FBMC can be a suitable waveform result for 5G mobile communications.

5.2 Future Scope

Several researches and discussions are going on across the world among technologists, researchers, academicians, vendors, operators, and governments about the innovations, implementation, viability, and security concerns of 5G. As proposed, loaded with multiple advance features starting from the super high speed internet service to smooth ubiquitous service, 5G will unlock many of the problems. However, the question is in a situation, where the previous technologies (4G and 3G) are still under process and in many parts yet to be started; what will be the future of 5G? 5^{th} generation technology is designed to provide incredible and remarkable data capabilities, unhindered call volumes, and immeasurable data broadcast within the latest mobile operating system. Hence, the various candidate waveforms are available for the 5G system, some of them are OFDM and FBMC. These two waveforms are widely used and we can use the different modulation techniques to vary the performance of the system according to our need. In future, to reduce the some limitations of OFDM and FBMC other candidate waveforms can be used as: the UFMC and GFDM etc.

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