COMPARATIVE ANALYSIS OF FBMC OVER CP BASED MIMO OFDM SYSTEM AND PAPR IMPROVEMENT OF FBMC USING HYBRID TECHNIQUE

A Thesis Submitted in Partial Fulfilment of the Requirement for the Award of the Degree of

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DECLARATION

I, Manik Zakhmi hereby declare that the work presented in this thesis entitled "Comparative analysis of FBMC over CP based MIMO OFDM system and PAPR improvement of FBMC using hybrid technique" in partial fulfilment of the requirement for the award of degree of Master of Engineering (ECE) submitted at Electronics and Communication Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of Dr. Ankush Kansal (Assistant Professor, Electronics and Communication Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University) from 2016 to 2018. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

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ABSTRACT

Filter bank multicarrier (FBMC) has emerged as the favourite multicarrier communication technique for the fifth-generation communication systems. Since it meets the demands of the next generation standards. The achievability of high data rates (10 Gbps) is expected to be attained by the 5G technology. This requires larger bandwidth and efficient usage of the frequency spectrum. Also, to utilize white space, cognitive radio networks are needed. In cognitive radio network very low out of band radiation is desired. To overcome the problems of low spectral efficiency and high out of band radiation in OFDM systems, FBMC is chosen to be a suitable choice. n this thesis FBMC is used as a waveform candidate for 5G communication. High PAPR is always a problem in multicarrier communication system. FBMC is also a multicarrier communication system, so it also suffers from high PAPR problem. To reduce the PAPR several PAPR reduction techniques have been proposed over the last few decades.

In this thesis, a hybrid technique formed by the combined application of Selected mapping (SLM) and Partial transmit sequence (PTS) is proposed for minimising the PAPR.The two conventional techniques are united in a way such that the meritorious qualities for both are highlighted It gives significant performance improvement compared to the SLM and PTS techniques taken separately. A comparative BER analysis for FBMC and CP-OFDM is done. For this scheme simulation is performed to analyze the PAPR performance of FBMC system with various PAPR reduction techniques. All the simulations are performed in MATLAB.

TABLE OF CONTENTS

LISTS OF THE TABLES

LISTS OF FIGURES

LISTS OF ABBERVATIONS

ACE	*Active Constellation Extension*
BER	*Bit Error Rate*
BFDM	*Bi-orthogonal Frequency Division Multiplexing*
BS	*Base Station*
CCDF	*Cumulative Complementary Distribution Function*
CMT	*Cosine Modulated Multitone*
CR	*Cognitive Radio*
DSL	*Digital Subscriber Line*
FBMC	*Filter Bank Multi Carrier*
FDM	*Frequency Division Multiplexing*
FMT	*Filtered Multitone*
GFDM	*Generalized Frequency Division Multiplexing*
ICI	*Inter Carrier Interference*
IOTA	*Isotropic Orthogonal Transform Algorithm*
ISI	*Inter Symbol Interference*
LTE	*Long Term Evolution*
MCM	*Multi Carrier Modulation*
MIMO	*Multiple Input Multiple Output*
OFDM	*Orthogonal Frequency Division Multiplexing*
OQAM	*Offset Quadrature Amplitude Modulation*

PAM	*Pulse Amplitude Modulation*
PAPR	*Peak to Average Power Ratio*
PHYDYAS	*Physical layer for dynamic spectrum access and cognitive radio*
PTS	*Partial Transmit Sequence*
TDM	*Time Division Multiplexing*
QAM	*Quadrature Amplitude Modulation*
SLM	*Selected Mapping*
TI	*Tone Injection*
TR	*Tone Reservation*
UFMC	*Universal Filter Multi Carrier*
UWB	*Ultra-Wide Band*
VSB	*Vestigial Side Band*
5G	*Fifth Generation*

CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

This chapter corresponds to the presentation of a brief summary of the research work, pertaining to the short description regarding the potencies for its motivation. After that, the main objectives for the thesis have been presented, followed by the organization structure of the thesis.

The wireless cellular communications have progressed apace since the last two decenniums. It began with the second generation of mobile communications from 2G Global System for Mobile (GSM) to the fourth generation referred to as the 4G Long Term Evolution-Advanced (LTE-A) systems. Owing to the ever-increasing users demands, the need for larger bandwidth and least latency levels emerged as a consequence. It necessitates that the next generation communication systems which should be capable enough to meet the current day demands, for instance inter channel interference (ICI), energy efficiency, scalability, connectivity and they should be compatible with the legacy networks.

It became possible to enjoy real time video calling because of greater data speeds on account of the advanced technology that introduced the 3G Universal Mobile Telecommunication System (UMTS). The accessibility for channelization of triple play traffic, where the data, voice and video, all being inclusive were attained. The generations of wireless communications made headway for digitalization by introducing the 2G as the foremost standard for mobile voice communication. Whilst the third generation (3G) was regarded as the first standard for mobile broadband, since it was designed with additional features for multimedia services. It has been observed that in 4G data rates have reached 50-100 Mbps, while 2Mbps speed has already been attained at the advent of 3G communications. The services of 3G introduced the digital communication scenario providing 64kbps in the second generation of cellular networks. The expectations from the fifth-generation networks are enormous, in terms of enhanced scalability, data rates, reliability, higher throughput, low latency, and its energy to be efficient enough to provide connectivity to the network. With the ever-increasing users and devices, the numbers are predicted to touch around 50 billion which would be connected to the IP network globally is intriguing [1]. The spectrum seems to be scarce for there is need to accommodate vast services and the demands for higher consumption of energy. This situation urged the desires to initiate the research for the suitable standards to support the fifth generation of technologies. The fifth-generation mobile standard represented by 5G, which is beyond 4G and LTE-Advanced. The technology will be approaching to Internet of Things (IoT) providing access to the Real time control operations, where the appliances will be controlled by the remote over the 5G network.

It was realized that the traditional single carrier systems were not competent enough to meet huge data rate requirements due to the hindrances posed by the multipath channel effects and complex receiver diversity. With the objective that the data requirements are met and the Inter symbol Interference (ISI) caused due to the dispersive channel impulse response, multicarrier modulation systems came up as the reliable alternative for an improved present and a secured future of wireless generation networks. In this modern era of development in technology, multicarrier modulation has become a key technology to ensure the accretive necessities of people, which include eminent data rates and prerequisites of the quality of moving freely that supports the applications of wireless systems. In today's digital world scenario, among all the MCM techniques, the CP-OFDM has predominantly ruled the wireless communications [2]. OFDM is a widely adopted technique for high speed wireless communications such as IEEE 802.11a/g/n, IEEE 802.16a/d/e, IEEE 802.20, and ETSI BRAN, ADSL, DVB-T/H, LTE, TDLTE and other standards under fourth generation of communication technologies. The OFDM systems have gathered immense attention due to the fact that they are immune to impulse noise and multipath fading, persuading to get rid of equalizers. Also, the utilization of Fast Fourier Transform technique form the basis for the effectual hardware implementation.

1.2 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

OFDM is based on the principle of multicarrier modulation. In multipath, propagation, the spreading in the signal is spread in time domain that causes inter symbol interference (ISI). In OFDM technique, the system bandwidth is divided into sub bands and these sub bands are orthogonal and independent to each other. In OFDM the data is firstly divided into independent stream. This independent stream modulates with different subcarriers and then multiplex to create OFDM signal.

OFDM is a special case of frequency division multiplexing. This technique saves up to 50% of the total spectrum than FDM technique. It helps the system to offer robust and persistent communications, overtaking the noise and interferences from adjacent signals and promoting the efficient usage of the available bandwidth.

Basically, OFDM technique is used to convert frequency selective channel to flat fading sub channels. The data stream having high speed gets distributed into multiple narrowband streams and gets transmitted parallelly over different subcarriers. The symbol duration for each symbol is increased by the Cyclic-Prefix (CP) reduces the effects of ISI. To overcome the effects of ISI, the receiving end needs to be supplied with a one tap equalizer. The CP being appended at the end of the symbol transmitted so that channels having multiple paths are not affected by the delay spread. Since the Doppler shift exists, frequencies are not synchronized and with the incorporation of CP, the overall system becomes less spectrally efficient. Also, the existence of inter carrier interference (ICI) cannot be neglected, which occurs due to the effects of Carrier-Frequency-Offset (CFO).

1.3 MIMO-OFDM

The multiple input multiple output orthogonal frequency division multiplexing refers to the use of multiple antennas at the transmitter as well as at the receiver. The union of MIMO with OFDM has been a promising alternative for the future high-speed wireless systems. The transmission of a signal via multiple paths are affected by the occurrence of fading, called multipath fading. The different signals reach at receiver have different time period because of multipath propagation. The fluctuations in the received signal caused due to the interfering multipath components leads to the phenomenon of angle spreading, delay spread and Doppler spread. Further, the scarcity of bandwidth spectrum and limited power constraints necessitates a future communication system competent enough to depend on for higher data rates and efficiency of spectrum [3]. The evolution of MIMO technology marks an important discovery in the cellular wireless communications design. It proves to overcome the channel and resource restraints, thereby offering copious advantages over the earlier wireless systems. Various benefits of the MIMO technology are listed below.

- Array Gain**:** Multiple antenna systems require the knowledge of the channel at either transmitter or receiver or at both to achieve array gain.
- Spatial multiplexing gain
- Spatial diversity gain
- Interference reduction and avoidance
- High data rate
- Reliable and robust transmission over the harsh wireless environment quality improvement

Despite the extensive recognition for the OFDM and MIMO-OFDM for the exploiting the multicarrier modulation schemes, it still has some shortcomings on its way. For sensing the channel, a high spectral dynamic range for the spectrum is required, which is not done properly by the OFDM systems. Spectral efficiency loss occurs because of the addition of cyclic prefix in the OFDM symbol. The systems seem to be extremely sensitive to timing and residual frequency offsets which can be generated as a result of Doppler effect and poor synchronization. Also, larger sidelobes occurs at each sub carrier caused by the rectangular impulse response. There is interference for other adjacent systems when subchannels are lying at the edges of transmission bandwidth. Due to these hindrances for implementation of OFDM systems, the researchers are provocative to extend their works towards the newer generation networks. The 5G is predicted to handle enormously large number of users, facilitate high mobility by reducing consumption of power and utilization of the spectrum proficiently. It demands for technologies supporting avalanche of traffic volume 1000× in a decennium and large variety of user cases and necessities.

The technical objectives for the fifth generation of wireless communication networks include up to five times lower latency and the end data rate reaching up to 10 Gbps. There will be requirement for accommodating 10 to 100 times greater count for the devices connected to the system at a particular time. The devices should be competent enough to sustain the developments in the newest technologies, for which the battery life of the devices plays an important role. The battery life is expected to be enhanced by 10 times. The features of designing 5G wireless systems are enlisted below.

- Higher Frequencies
- Device to Device Communication
- Fiber like user experience
- Massive MIMO
- Ultra-Dense Networks
- Massive machine Communication
- Ultra-Fast Switching
- Moving Networks
- Ultra-Reliable Communication

1.4 PROJECTS FOR DEVELOPMENT IN 5G

Since the developments in technology and new services and features for digital appliances being launched, there is remarkable raise in the number of users. The ubiquitous nature of mobile networks has grabbed the attention for it helps to be connected to each other at any moment of time. The users tend to enjoy the Real time connectivity services as the brownie points with respect to the technological upgradations. The futuristic technologies comprise of IoT and intelligent sensor networks, leading to a connected society. The counting of Internet connected devices will be reaching to about billions in number. It is required to accommodate the anticipated number of base stations with provisions for sustained connectivity for impenetrable diverse networks and thus the demands for real time traffic can be fulfilled. The researchers are working towards a society which promotes the idea of "Smart Living" [1].

The research groups are focussing on the research for 5G standards is the most looked upon area at this time. These groups base their research relating to the technical and probabilistic standards for the fifth generation of communication networks. These projects discuss the establishment of 5G networks considering all the aspects, hurdles and to make the best use of the available spectrum. Few of them are explained as follows:

- **METIS**

  It stands for the mobile and wireless communications enablers for the twenty–twenty Information Society. The Key performance indicators (KPI's) for the 5G have been addressed. According to the report formulated for this project, the testbed evaluations for the requirement of user data rates, the call traffic for different regions and each subscriber's traffic volume are investigated. Also, the traffic flow for various indoor and outdoor scenarios for Radio Access Networks (RAN) architectures have been presented. The research has been advanced by the upgradation to METIS-II project which provides ideation for the assessment of 5G RAN and global consensus building collaboratively.

- **5G-PPP**

  As per the 5G-PPP standards, the vision for 5G was defined by the infrastructure rich telecom services, providing first class incessant connectivity which will meet the competences for fixed and mobile access networks. In the research project started by the European Commission, they serve as the telecom operators and manufacturers.

- **5GNOW**

  The researches regarding ultra-high reliability, ultra-low latency and unified frame structures for the feasible waveform contenders for 5G were carried out in this project. It explained the signal expansion via the process of Gabor Signalling. The summation of the time and frequency shifted versions of the prototype filter constitute the expanded signal. The short-term Fourier transform (STFT), can help to understand the concept for the acquisition of time and frequency information.

- **EMPhatic**

  The project studies deal with the explorations for MIMO transmission, the evolution of filter banks, asynchronous techniques based on multi hop or relay-based communications. The proposition of the several approaches for MIMO transceiver structures relating to frequency selective channels for FBMC.

- **NEWCOM#**

  The research targeted to achieve the high-end possibilities for future wireless domain networks. It focusses on the effectivity of channel and energy requirements in the network along with the timeserving multi hop communications. There has been an exclusive research ongoing on the spectrum overlaid due to the coexistence of 4G/5G, broadcasting mobile services, Cloud-RAN, multi hop coding and the distributed antennae localisation.

1.5 PROMISING WAVEFORM CONTENDERS FOR 5G WIRELESS COMMUNICATION NETWORKS

The upcoming candidates for 5G mobile communication technology are FBMC, filtered OFDM, Generalised Frequency Division Multiplexing (GFDM), Universal filtered Multicarrier (UFMC) and Biorthogonal Frequency Division Multiplexing (BFDM). The 5GNOW [4] has mainly considered these waveforms for provision of an efficient interfacing in wireless domain. Due to greater capabilities of FBMC, it is set to bring about an emphatic change in multicarrier systems based on the effectuation of filter banks. However, the OFDM symbols sacrifices with the spectral efficiency due to cyclic prefix insertion and has low efficiency contributing in greater out of band radiation. So, to make sure that these issues are subdued, offset quadrature modulation (OQAM) based FBMC is regarded as a promising modulation technique superseding the older CP based OFDM in the physical layer of next generation communication systems. The capabilities to suppress the sidelobes via filter banks in FBMC, makes it a top most choice for to attain spectrally efficient system.

- **FBMC**

  The filter bank based multi-carrier (FBMC) scheme constitute of filter banks at transmitter and receiver. The fifth generation communication is anticipated to set into motion by 2020 and FBMC will be one of the suitable candidates as the multicarrier technique used is resistant to intersymbol interference and fading caused by transmission in comparison to OFDM used in 4G. Lower side lobes can be achieved by implementing the combination of FBMC with OQAM modulation [5].Due to its enhanced power to carry the spectrum shaping flexibly and by achieving maximum bit rates and spectral efficiency with increased robustness, FBMC has been progressively favoured [6-7]. The property of time frequency localisation (TFL) pulse shaping is well utilised by the filter banks based on IFFT/FFT. The subcarriers are laden with OQAM symbols that are staggered and symbol rate of real symbols being doubled [2]. There is no need of Cyclic Prefix in FBMC/OQAM systems, instead various filters are used. In the research for telecommunication services, FBMC is found to have its deep roots since long time. A well localised pulse shaped frequency has been put into use for each sub carrier, so that the out of band (OOB) leakage is minimized. This enables allocation of large number of subcarriers in the allotted frequency band. It has proved to be a leading contender for fifth generation wireless communication systems.

- **GFDM**

  In Generalised Frequency Division Multiplexing (GFDM), the individual sub carriers are circularly pulse shaped enabling the blocks to form the basis of transmission. GFDM, being a non-orthogonal multicarrier modulation technique, allows multiple symbols to be transmitted per sub carrier. It was proposed with the objective to cope up with the growing demands in wireless cellular networks for incessant machine to machine communication by utilization of spectrum in a way such that it avoids the wastage of resources. For short burst applications, GFDM is a preferred alternative among the other enhanced physical layer schemes grounded on the processing of filter bank. The application of pulse shaping filters with varied lengths makes it favourable for the reduction in out of band radiation and the ISI and ICI can be dealt easily through the insertion of cyclic prefix. The compliance of GFDM with OFDM can be realised when the transmission is carried out by considering the number of subcarriers [3]. The BER performance for GFDM is similar to that of OFDM, whilst the usage of pulse shaped sub carriers directs the out of band radiation reduction and thus downplays the effect of interference for the multicarrier system.

- **UFMC**

  Universal Filtered Multi carrier Modulation (UFMC) can be considered as a reliable scheme for multicarrier transmission of data. It has grabbed the attention due to the fact that it has improved provision for sub carrier separation like FBMC and its complexity standards are alike OFDM. UFMC has been presented as a novel waveform design, in which the waveforms are non-orthogonal in nature, so that better spectral efficiency and low latency are attained. Since each subcarrier gets filtered during the operation for FBMC, while a single shot filtering is carried out in the OFDM. The implementation of UFMC is performed by considering the best of the two schemes for multicarrier transmissions, thereby outperforming the two for few of its capability measuring parameters. The subsets of complete band get filtered instead of complete band being fed to the filtering process or each subcarrier being filtered. The length of the filter is dependent on the sub band width and a number of sub carriers are contained in each sub band [8]. This in turn, helps to obtain the advantage of better sub carrier separation, which is a feature inherited from FBMC and the lower complexity feature from the OFDM system.

- **BFDM**

  The perfect recovery of bi-orthogonal frequency division multiplexed symbols is possible by applying the approach of bi-orthogonality. This multicarrier modulation scheme lacks the orthogonality in pulses present at the transmitter and at the receiver, rendering it to be a weaker form of orthogonality. The method is appropriate for the symbol pulses of longer duration for the transmission to take place. BFDM is more robust in comparison to OFDM in terms of frequency offset in transmission. However, occurrence of spectral regrowth because of the periodic setting during the bi orthogonal pulses are calculated.

Table 1.1 OFDM versus FBMC Comparison Table

CP-OFDM	**FBMC**
• Rectangular pulse shaped filter is used, which is limited in time domain.	• The prototype filters used are PHYDYAS, IOTA, WHP etc. They are doubly localised isotropic filters.
• By employing IFFT operation, the implementation of OFDM systems is simplified.	• Basic structure of FBMC appears to be more complicated than that for OFDM, but efficient implementation is exhibited by exploiting the Polyphase network (PPN) structure.
• There is requirement for cyclic prefix insertion and due to that throughput is minimized.	• The Cyclic prefix insertion is avoided, thereby leading to increased throughput.
• The side lobes for the prototype filter are larger in frequency domain.	• The prototype filter has improved spectral confinement and lower side lobes.
• The doubly dispersive channels cause erroneous transmission.	• FBMC Systems are robust against the doubly dispersive channels.
• There has already been establishment and development of adaptive modulation schemes, synchronization and equalization schemes.	• The research on adaptive filter bank structures, synchronization and equalization issues are under progress.
• The perfect synchronization in carrier and symbol time is requisite.	• The demands for perfect carrier and symbol time synchronization are not rigorous.

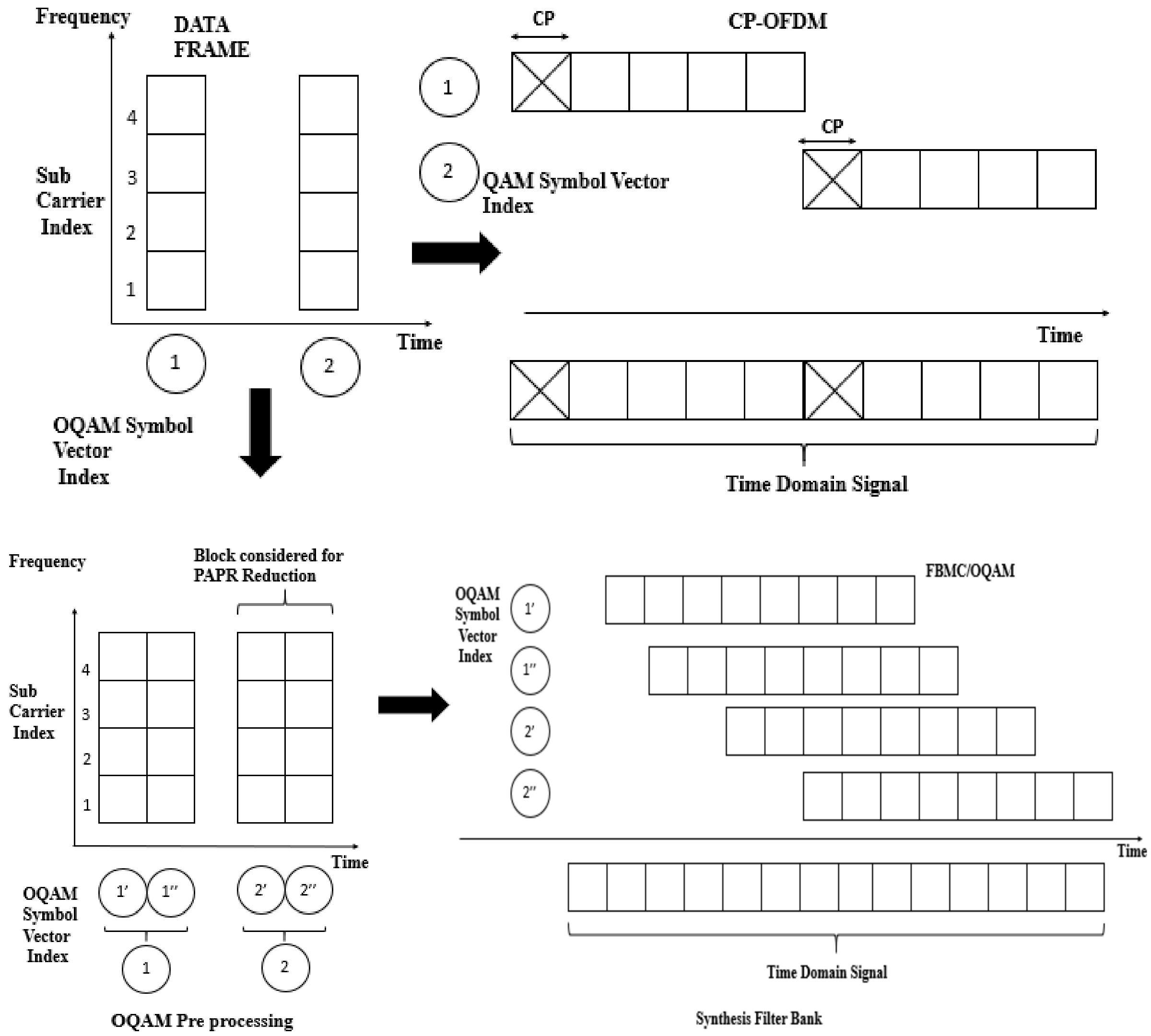

Figure 1.1: Transmission of blocks comparison for CP-OFDM and FBMC

1.6 ADVANTAGES OF FBMC

- The FBMC-QAM system proves to have a great potential in allowing for seamless utilizations of conventional transmission techniques used for legacy OFDM- QAM systems.
- FBMC provides spectrum efficient and more selective system.
- Insertion of Cyclic Prefix is not required in FBMC and hence it conserves bandwidth.
- It also provides robust narrowband jammers.
- Large sidelobes in OFDM as compared to FBMC for frequency spectrum.
- To ensure correct detection at the receiver, Multiple access interference (MAI) cancellation should be performed in OFDM. In FBMC, MAI is suppressed due to excellent frequency localization of subcarriers.
- In OFDM, carrier frequency offset is highly sensitive. FBMC however is less sensitive and hence performs significantly with the increase of the user mobility

- It has high flexibility while adopting MIMO techniques, while OFDM are less flexible for MIMO.
- Due to spectral leakage in OFDM signals, the spectrum sensing performance gets degraded. There is high spectrum sensing resolution in FBMC.

Although FBMC promises to provide all the luxuries one could expect from the multicarrier techniques, still it is affected by the peak power problem. The Peak-to-Average-Power problem caused by the highly varying amplitudes of the transmitted signals. The efforts to cause its diminution are explored to allow ceaseless communication.

1.7 OUTLINE OF THESIS

This thesis is organized into six chapters. The foremost chapter stretches to the introduction of 5G technology in the wireless cellular domain. The main goals and objectives for the thesis research have been conferred, followed by the brief description of thesis arrangement.

In the second chapter, the survey on the implementation of FBMC/OQAM Systems are presented. The various contenders competent enough to meet the requirements for the new generation network systems have been presented. A study for PAPR reduction schemes for the 5G multicarrier systems is considered for the literature survey. Also, the hybrids proposed so far by combining the different conventional schemes have been analysed.

The third chapter presents the technical background and detailed explanation for the filter bank multicarrier systems. It elaborates and justifies the suitability of FBMC/OQAM systems for the fifth-generation networks. In addition to this, it also compares the implementation of multicarrier systems using traditional OFDM systems and new-fangled scheme called FBMC/OQAM through study for the prototype filter utilized has been discussed in this chapter.

The high peak to average power ratio (PAPR) is an intrinsic drawback of multicarrier systems caused deterioration in the signal. The discussions for various PAPR Reduction techniques which can be applied for PAPR reduction in 5G are presented. The Hybrid scheme referring to the union of SLM and PTS has been proposed and analysed.

In the fourth chapter PAPR performance is analysed for the novel technique proposed by the combination of conventional Selected Mapping and Partial Transmit Sequence techniques. The analysis results after the simulation are exhibited and conferred.

The fifth chapter, being the concluding chapter of the thesis, summarizes the conclusions obtained regarding each chapter and the possible directions for the scopes of the future work are presented.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This section overviews the work which has been done regarding the multiuser MIMO from time to time. Various methods and techniques have been discussed and proposed, which provide an insight into the 5G Wireless communications. Also, the study for various techniques for PAPR reduction is presented.

2.2 LITERATURE REVIEW

Investigations for the allocation of time frequency resources acquirable with flexibility for the upcoming generations of wireless technology have been done by Ronald Nissel *et al.* [9]. It is seen that due to the scarcity of spectrum, ideal implementations with conventional CP based OFDM systems for efficient bandwidth usage is an arduous task. So, with the objective to make proper usage of frequency spectrum, there emerges a need for employing some modifications thereby leading to filtering or the application of windows. In the work carried out by the authors, it is observed that the performance of Filter Bank Multicarrier Systems has been compared the predominant OFDM systems, providing higher spectral efficiency. The estimation of channels and usage of multiple antennas have been intriguing and the interests associated with FBMC by the real-world testbed measurements are addressed. If the pulse shaping is matched to the channel statistics, the equalizers with one tap are sufficient for implementation practically. For doubly dispersive channels, the closed form solutions for signal to interference ratio are derived to make the system more robust.

Wafa Khrouf *et al.* [10] proposed an epitome based on ping pong optimized pulse shaping (POPS) as a coercive method for the generation of multicarrier waveforms such as in the filter bank multicarrier (FBMC/OQAM) scheme, assuring the favourable signal to interference plus noise ratio (SINR) at the receiving end. The investigations are based on the designing of multicarrier transmissions over the channels having strong delay spread and are apace time variant. The reduction in ICI and ISI levels achieved after applying the POPS paradigm is prominent. The analytical results for the SINR have been studied and the performance metrics of the FBMC/OQAM turned out to be better with those for the FBMC/QAM modulation for some parameters. Also, it is reported that implementing systems with OQAM modulation increases complexity. The SINR gains reach about 7dB have been obtained from the waveforms optimized for eminent dispersions with respect to the PHYDYAS filter waveforms as employed in FBMC/OQAM systems. The out of band emissions resulted from PHYDYAS was far better than those of Isotropic Orthogonal Transform Algorithm (IOTA).

A proposal for a parallel equalization structure was put forward in this work for compensation of channel frequency selectivity by Francois Rottenberg *et al.* [11]. The effective implementation of FBMC/OQAM systems have been studied in the presence of doubly dispersive channel. Due to the enhanced selectivity of channel in time and frequency, it is observed that it spifflicates the orthogonality in symbols leading to distorted signal at the receiver. In this work, the authors have performed investigations on the time and frequency selectivity of the channel. As per proposed structure design, utilizing multiple analysis filter banks at the receiver can help in achieving a system prone to ISI and ICI, which follows the derivation for the noise power and distortion occurring residually to an approximate value. Higher efficient systems are obtained as a result of exploiting the proposed receiver structure and the verifications for the performance of the FBMC-OQAM systems were also done.

Ali Jasim Ramadhan [12] discussed the prototype filter designed for the fifth generation Filter Bank Multicarrier systems implementation. The shortcomings occurred in the former technologies led to increased latency and enhanced symbol lengths without affecting channel capacity. The utilisation of PHYsical layer for Dynamic spectrum access and cognitive radio (PHYDYAS) filters minimised the problems suffered in fourth generation networks by incorporating the filter banks at the transmitter as well as the receiver. It is noticed that the higher side lobes leading to greater amount of ISI, ICI, OOB and PAPR.So, in order that the channel gets exploited effectively the cyclic prefix have been removed and the symbol length is shortened. By implementing PHYDYAS filter, with overlapping factor (K=4), the system possesses high spectral efficiency.

Bidyalaxmi Devi Tensub *et al.* [13] provides an overview of the multicarrier modulation schemes competent enough to meet the requirements of the future telecommunication areas. It discussed the techniques dominating the wireless communications till now and their downsides. The technology approaching to the implementation of filter banks in which Fast Fourier Transforms forms the basis for the development of sub bands being processed. The applications such as cognitive radio (CR), Multiple Access Networks, TVWS, PLC, and MIMO communication are witnessed to have overstepped the OFDM scheme. The idea of putting FBMC systems into practice has offered the spectrum to be more spectrally efficient, robust and the protection of spectrum, but at the cost of enhancement in complexity.

The issue of channel equalization in FBMC has been addressed by Tero Ihalainen *et al.* [14]. The proposed equalizer design formed the fundamental basis of the finite impulse response per subchannel, following the frequency sampling approach for both single input multiple output (SIMO) receive diversity and MIMO spatially multiplexed for FBMC/OQAM systems. The subcarrier-wise coefficients of equalizers were derived based on the computation for the number of frequency domain points lying within the bandwidth of a subchannel. The computational complexity and the performance metrics regarding the error rate for the scheme suggested were calculated for the equalizers design. It is observed that the proposed method provided compensation for the frequency selective nature within the subchannel and performing equivalently as the optimum MMSE equalizer, with the same error rate performance as that for an optimum MMSE equalizer. The proposed method allows a trade-off between the number of subchannels and order of their equalizers which renders the negotiable system level parameterization.

An introduction to the novel method for estimating the channel in Filter Bank Multicarrier technique by employing the scattering of pilot symbols was given by Wenjia Cui *et al.* [15]. The intention behind this scheme was to eradicate the imaginary interference on each pilot symbol, referred to as coded auxiliary pilot (CAP) method. Although, the OFDM based systems utilized the scattered pilots for channel estimation requirements but they did not prove to be functional for FBMC/OQAM systems since the real and imaginary symbols are transmitted differently in time frequency space. It facilitates few of the auxiliary pilot symbols for imaginary interference elimination while some of them are coded to carry information symbols, so that the high spectral efficiency demands are also met, keeping in mind its coding /decoding complexity. It was observed that the method discussed in this work for interference cancellation can efficiently perform well for two coded auxiliary pilot symbols with scattered pilots for the PHYDYAS filter while IOTA filter required four CAP symbols to exhibit similar performance.

Daiming Qu *et al.* [16] presented an approach for tail shortening applied on the FBMC/OQAM symbols, leading to the spectrum being more spectrally efficient. It is realised that FBMC systems have faced criticism since there were long ramp up and ramp down tails appended in the starting as well as at the ending of each symbols and caused the inefficient utilisation of spectral resources. So, a novel technique based on the virtual symbols appending was proposed. It was implemented by reducing the tail size through the inclusion of appending virtual symbols carrying no data to the beginning and termination for each of the symbols. The suppression of these ramp up and down tails can be carried out by picking up these symbols aptly. The extended simulations carried out were demonstrated with a tail overhead of T/4 on each side. The method suggested shortened signal burst length for an FBMC-OQAM packet ameliorating its spectral efficiency, for now it will lead to transmitting the same data in less time. The simulation result obtained by employing the optimization method depicts the higher out of band emissions and error vector magnitude values are lower for the symbols received after demodulation. Also, a slight change in PAPR values resulting in tail overhead.

Han Wang *et al.* [17] proposed a hybrid PAPR reduction scheme which constituting of partial transmit sequence and tone reservation for FBMC/OQAM systems. The authors discussed the favours bestowed on us by the exploitation of multicarrier techniques as given by the FBMC/OQAM systems. However, the inalienable drawback of obtaining higher peaks in the form of high PAPR is a major hurdle. The study about alleviation of PAPR proposed earlier by applying the conventional reduction methods have been produced. It was found that processing the two techniques together reduces the PAPR values to a greater extent. Also, another scheme was proposed which exploited multiple neighbouring overlapped data blocks, known as the M-hybrid scheme. It was observed that the M-hybrid scheme performed far better than the conventional hybrid scheme performed in this work. When compared to the conventional schemes, their hybrid simulated results introduced least distortion accompanied with lower computational analysis.

Analysis for PAPR reduction techniques for various multicarrier modulation schemes for the next generation wireless networks have been carried out by *Pooja Mehta et al.* [18]. The need for multicarrier modulation has been discussed and their numerous advantages are being looked upon, such as robustness against multipath propagation, scheduling multiple user and high quality of service etc. The suitability of OFDM as a multicarrier modulation technique for future broadband networks has been verified. The researchers have analysed the methods to make the spectrum spectrally efficient, thereby supporting huge data rates. It comprises of various methods designed to minimise the PAPR, including PTS, SLM, TR, Companding, Clipping and Filtering.

Mahmoud Aldababseh *et al.* [19] discussed the estimation of channels in FBMC/OQAM Fading using Dual Kalman Filters. They presented a standard solution for estimation by utilizing the least square estimator (LS) or the minimum mean square error (MMSE) estimator with the adaptive implementation using recursive least square(RLS) algorithm or least mean square (LMS) algorithm. Nevertheless, the fading channel statistics cannot be well exploited by these adaptive filters. In order that the advantages of adaptive filters are achieved, there is need for autoregressive process for the modelling of time evolution for the fading channel and tracking it by Kalman filter. The simulations exhibited its superior performance and are based on the estimations for fading channel coefficients. The effectiveness of the proposed technique using dual Kalman filters is then verified and compared with the pre-existing LMS, RMS techniques.

Nisha Varghese *et al.* [20] discussed the MMSE single tapped equalizer in FBMC-OQAM system in the frequency domain. In this work, the author has put light on the most popular scheme for multicarrier techniques highlighting its disadvantages and how they can be corrected. There has been spectral leakage due to the addition of the cyclic prefix at the end of each symbol. With the objective to deal with these drawbacks and move towards a better suitable candidate. The filter banks used in FBMC/OQAM are exponentially modulated for a single prototype filter. The prototype filter design implemented through frequency sampled method. The BER performance was studied for AWGN, pedestrian B and vehicular A channel for both equalizers and without equalizers.

It is observed that during execution of FBMC/OQAM, there is occurrence of residual interference comprising ISI and ICI since the orthogonality conditions are not met with only two filters. This in turn, demeans the BERs and creates a problem to achieve channel coefficients at reference symbols accurately. So, a new method was proposed by Beom Kwon *et al.* [21] for channel estimation in FBMC/OQAM systems, providing utility in evolved multimedia multicast system (eMBMSs). An even biased RS configuration was studied in the literature for MBSFN. The system uses separate prototype filters for even and odd number of subcarriers to maintain the orthogonality. While estimating the channel, the residual interference is modelled in a closed form over a multipath channel so that its influenced is alleviated. There is effective cancellation of interference with respect to the reference on the basis of the approximations for residual interference calculated earlier. It was found after the simulations were carried out that on employing the method proposed, the eMBMSs performance upgraded considerably, along with better mean squared error and raised the effective data rate.

The existence of channels which are eminently selective in frequency for the FBMC/OQAM systems designing of transmitters and receivers have been discussed by Màrius Caus *et al.* [22]. A new sub band processing scheme was proposed for designing two MIMO FBMC schemes. The signal to leakage plus noise ratio (SLNR) and signal to interference plus noise ratio (SINR) are the parameters that form a major part in design were proposed. The authors have observed that values improved values as the order of the spatial filters was increased. The overall performance metrics for most of the parameters, the FBMC/OQAM system overpowers those for the pre-existent MIMO OFDM systems. All the benefits of FBMC can be experienced in multicarrier modulation system but only at the cost of increased complexity.

Frank Schaich *et al.* [23] performed a comparative analysis regarding the multicarrier waveforms for the current as well as next generations approach for wireless communications. The waveform contenders worthy for low latency and shorter packet transmissions are discussed. The authors work comprised of the filtered CP-OFDM being the fourth-generation choice, new contenders such as filtered bank multicarrier (FBMC) and universal filtered multicarrier (UFMC) schemes. These are compared on the basis of time frequency efficiency for transmission of long sequences.

Pooyan Amini *et al.* [24] proposed an optimized cost function for filter bank multicarrier technique in doubly dispersive channels, with objective that robust performance is obtained. The authors gained motivation to work in this field through the requirements in doubly dispersive underwater acoustic communication channels. For UWA communications generation of symbols via FMT proved to be an outstanding method. Comparisons of proposed technique were done with respect to the OFDM, which resulted in better SINR values for the new generation FBMC systems. The validation and confirmation of the results was done theoretically by execution through (ACOMM10) real test-based simulations.

It was realised that the efficiency of the system gets shoddier in terms of power due to the existence of high Peak to Average Power (PAPR) in FBMC-OQAM systems. V.Sandeep Kumar *et al.* [25] addressed this issue to minimize PAPR by using the Tone Reservation scheme. Since the nature of FBMC symbols is dissimilar to that of OFDM in terms of the symbol overlapping structure, the application of direct TR technique was futile. So, FBMC-OQAM signals, sliding window tone reservation active constellation extension (SW-TRACE) technique was proposed which brought sliding window with Active Constellation Extension into use for this purpose. The peaks of an FBMC-OQAM signal get cancelled inside a window through the peak reduction tones (PRTs) obtained from numerous successive blocks of data. In order that the peak magnitude gets minimized, there is vigorous extension for outer constellation points in channels carrying data, constrained within margin-preservation. The analysed results were compared to the prevailing Tone Reservation (TR) technique for FBMC/OQAM system and it was noticed that the technique proposed, SW-TRACE outperforms the conventional one, and having lower computational complexity.

Adnan Zafar *et al.* [26] presented an approach to design a spectrally efficient MIMO based FBMC system which truncates the filter outputs. The authors have focussed on the long filter tails which tend to deteriorate the system performance causing overheads and arise generally during the implementation of FBMC-OQAM systems. The filter Output truncation was suggested as an alternative to abandon the filter tails, but at the cost of loss in orthogonality and thereby leading to introduction of ISI and ICI in the multicarrier systems. Also, a compensation algorithm was proposed further with the objective to detect the symbols at the receiver accurately and improve the SIR values associated with each symbol. By the virtue of analysis, it is observed that the advantageous insights of the filter having finite length and the spectrum gets highly efficient by employing the proposed algorithm for compensation.

Nuan van der Neut *et al.* [27] has presented novel techniques for PAPR reduction in FBMC-OQAM systems. The prevailing active constellation extension (ACE) methods for MIMO OFDM systems are extended to their implementation for the fifth-generation systems i.e. FBMC. It is observed that there is substantial rise in the Reduction capabilities for the FBMC-OQAM systems by employing the methods suggested. It proves to be an ideal choice for burst transmissions. On the basis of the simulated analysis, the proposed method for FBMC justifies its viability for the better imminent technology.

Zhen He *et al.* [28] proposed a scheme to deal with the high PAPR problem in FBMC-OQAM Systems. The scheme is known as Extend Candidate Transmit Sequences (ECTS), which helps to fight the issue for there is an overlapped structure of FBMC-OQAM and resolve the high PAPR values. Considering the overlapping structure of FBMC-OQAM signals for the scheme proposed in order that the candidate sequence sets are extended, the candidate transmit sequences to be applied are combined linearly. The applicability of the scheme was verified and it was found that it attained amended PAPR values, which resulted in comparatively reduced PAPR count as that for the conventional schemes.

It was observed that the wireless communication today is ruled by the transmission of data in the packet form, which are synchronized with the receiver through the signal's carrier frequency. It is necessary to ensure incessant communication so that channel impulse response is identified. Peiman Amini *et al.* [29], carrying forward the legacy for same philosophy discussed packetization to be implemented on the filter banks utilised in the filter bank multicarrier communications. The proposed methods are for applicable to carrier and timing tracking loops and the algorithms associated with channel identification and equalizers adjustment. It was seen that the tracking algorithms were put into use for resolving the timing offset and residual results obtained by performing the simulation have been verified and studied.

Tobias Hidalgo Stitz *et al.* [30] analysed the methods for synchronization process forming the basis for the FBMC-OQAM communications. All the parameters for system to be effectively set up corresponding to the, synchronization, channel estimation, and equalization methods were considered. It was observed that accurate estimation of channel response, the carrier frequency offset (CFO) and fractional time delay (FTD), were obtained by employing the explicitly formulated pilots for filter bank multicarrier modulation technique. Further, an innovative combination of FTD and channel estimation scheme was suggested. For cognitive radio and spectrally agile scenarios, the parameters such as channel and compensation in frequency domain was carried out effectively.

Daiming Qu *et al.* [31] presented the idea for the joint optimization of multiple blocks for the reduction of PAPR in FBMC-OQAM signals. The author has studied multi-block joint optimization (MBJO) scheme which was implemented by proposing improvements in the PTS technique, named as MBJO-PTS scheme. Moreover, two algorithms were looked upon to be work out to combat the optimization in MBJO-PTS. The exploitation of the proposed dynamic programming (DP) Algorithm guaranteed an optimal solution and outperformed the conventional PTS scheme for reding the PAPR by 0.9 dB at CCDF of 10^{-3}, when operated for same number of subcarriers and the other parameters being kept same.

S. S. Krishna Chaitanya Bulusu *et al.* [32] discussed the issue of high PAPR in FBMC-OQAM. In spite of being a viable alternative for the upcoming 5G, it has inherited an issue from its predecessor technologies. The work carried out by the authors mark the importance of implementing the trellis based selected mapping scheme for FBMC-OQAM systems. The analysis for the scheme proposed is based on the computation complexity, the issues of latency and the hardware memory. The performance, metrics for the above discussed scheme measured the impact of duration for time of partial PAPR performance. The simulation exhibits the lower amount need for hardware and improved PAPR values are yielded by employing the proposed low latency TSLM.

An introduction to the analysis for studying the impact of high power amplifiers (HPA) nonlinear distortion (NLD) for multicarrier modulation schemes was given by Hanen Bouhadda *et al.* [33].]. By considering the FBMC-OQAM and OFDM, the authors have investigated the BER performance over different channels such as AWGN and Rayleigh channel models. For various HPA models, the BER values were computed and plots were obtained. The theoretical expressions to calculate the BER for generalised HPA models were derived on the basis of a polynomial fitting method.

Ari Viholainen *et al.* [34] concentrated on designing of a prototype filter for the transmission of signals through the Filter Bank Multicarrier scheme. It highlighted that the prototype filters based on near perfect reconstruction, represented as closed form considering few adjustable parameters has proved to be advantageous by selecting the frequency sampling technique. The main objective was to measure the performance trade-offs attained by application of diverse optimization methods. The work proposed comprises of the detailed comparison of various prototype filters for stopband, passband values due to the frequency selective nature of FBMC-OQAM symbols. Also, there can be an extension in the work which puts into use novel criteria for improving the performance and optimization.

Md. Motahar Hossain Mishu *et al.* [35] focussed on the effectiveness of FBMC-OQAM systems for the forthcoming fifth generation of wireless broadband networks. It has been realised that OFDM is not a preferred alternative technique for the 5G communications for it causes leakage in the spectrum and its requirement for strict temporal and frequency synchronization. Also, the high PAPR in all multicarrier systems calls for concern to obtain enhanced transmission of data for the upcoming wireless networks. The study introduced the FBMC-OQAM technique which supersedes CP-OFDM and analysis regarding BER, PAPR reduction capabilities and computational complexities were determined in the combined presence of channel impairments of shadowing, loss due to channel, path loss and Nakagami fading. The simulations indicated FBMC for performing the BER calculation to be a better choice for implementation.

Chun-Yi Liu *et al.* [36] discussed the polyphase network (PPN) design for FBMC-OQAM system at 60 GHz band, which is based on the reordered memory access. It was found that the novel method suggested for the Implementation of baseband designs had slightest complexity. The evaluation of the system design for complexity of hardware was determined by employing the proposed PPN into 8X parallelism 60 GHz band for baseband receiver. The simulated results for Out of band (OOB) radiation in fixed point showed great upgradation. Also, there is data rate increment by 52%, followed by establishment of FBMC-OQAM at the baseband receiver.

Hong-Jie Chou *et al.* [37] considered the effect of high PAPR during the transmission of signals in the Orthogonal Frequency Division multiplexing (OFDM) systems. It was observed that increased values for PAPR led to the increased cost of radio frequency power amplifiers that deteriorates the system. The authors have proposed a modified hybrid scheme which combines the two conventional reduction schemes such as selected mapping and partial transmit sequence for the OFDM systems. Generally, PAPR Reduction performs better when the number of IFFT subcarriers is large. The investigation was carried out for both conventional hybrid as well as the modified one as proposed. The simulation results exhibited better reduction performance in terms of PAPR and lower computational complexity as obtained from proposed modified hybrid technique.

Tanja Karp *et al.* [38] discussed the modified DFT filter banks with perfect reconstruction for implementing the Filter Bank Multicarrier systems. The authors have presented the detailed linear phase analysis of the filters, which are put into use at the transmitter and at the receiver. The synthesis filters are derived from an appropriate zero phase prototype filters. It was noticed that the MDFT filter banks provided perfect reconstruction for the same prototypes as for the cosine modulated filter banks. So, same methods for designing them can be considered. The work comprises of the input signal mappings into sub bands and the performance of the MDFT filters was compared to that for the cosine modulated filters.

2.3 GAPS IDENTIFIED

From the literature survey done above, following are the gaps encountered:

- It has been observed from reported literature that the synchronization of terminals and reduction in internal power consumption needs to be done.
- The use of cyclic prefix in the pre-existing OFDM systems was found to be spectrally inefficient [12]. The increased amount of inter carrier interference and out of band radiation forced the researchers to look for a suitable technology for future systems.
- The effective combination of transmit diversity scheme configurations such as (MISO) have posed challenges when the signal is subjected to FBMC modulation. The collaboration of above mentioned schemes with subchannels which frequency are selective in nature needs to be studied [14].
- The earlier CP-OFDM systems formed the basis of scattered pilots for estimating the channels but they can’t be applied directly to the FBMC-OQAM systems, since they require separate transmission for real and imaginary symbols in time and frequency space [15].

- The reduction scheme for minimising the PAPR values when employed using the tone reservation scheme, it was found that the power consumption increased manifold [17].
- Due to the insertion of CP in the OFDM systems, the spectral leakage occurred. So, filter banks are employed to meet the higher data rates and services for newer generations [20].
- The added overhead introduced by FBMC makes the integration of downlink synchronization, uplink sounding symbols and small uplink control messages are very inefficient [23].
- While investigating the implementation of FBMC technique on the basis of time SMT and CMT, it was found that there was more jitter in the carrier tracking loop while employing the CMT [29].
- The behavioural examination of smaller banks of filters for same bandwidth having greater spacing between subcarriers, for it may pose challenges for evaluation when the channel is not flat fading [30].
- In CP-OFDM Systems the increased PAPR values lead to increase in radio frequency power amplifier and deteriorating the system efficiency [37].

2.4 OBJECTIVES

The objectives for the thesis are enumerated as follows:

- To investigate the effectuation of the FBMC/OQAM and evaluate its BER performance by varying number of subcarriers.
- To examine different reduction schemes suitable to be applied for reducing PAPR in FBMC systems. The analysis for BER, PAPR, CCDF curves for the system model has to be carried out.
- To study and implement the selective mapping technique for PAPR reduction in FBMC/OQAM systems and development of a generalized algorithm transform with diminished PAPR values.
- To explore the partial transmit sequence (PTS) based PAPR reduction schemes and development of an efficient PTS techniques which will be deprived of side information for FBMC system model.
- To suggest a new mapping method for both PTS and SLM based on FBMC/OQAM systems. Exploring the proposed hybrid for PAPR Reduction and observe the comparison for its performance using traditional schemes.

2.5 METHODOLOGY

In this work, studies based on the CP based OFDM systems and MIMO OFDM systems are carried out. FBMC-OQAM is believed to be the heir of the current day network systems. The filter banks implementation was done after studying its basics. By exploring the studies for OQAM-FBMC, it is intended to implement the Filter Bank structures for the T_x and R_x,to obtain the increased data rates. The performance for FBMC systems for realising its effective communication in terms of the bit error rate for predefined SNR values in wireless domain for multicarrier systems. An issue poses as a major shortcoming while implementing MCM techniques, that refers to high peak power (PAPR). Various studies have been introduced for reduction in PAPR for the erstwhile, 4th generation network systems. The intention is to develop schemes for minimizing PAPR in (OQAM) FBMC.With access to knowledge, comes the potential to solve the problem. The applicability of PAPR reduction schemes using a hybrid technique has been verified for applying them to the FBMC systems. All the simulations are performed in MATLAB.

CHAPTER 3

FILTER BANK MULTICARRIER MODULATION

3.1 INTRODUCTION

The domain of telecommunication is an interesting area of research in current scenario. Multicarrier modulation has captured interests of researchers keen in telecommunication technology growth. The technology has upgraded to newer generations of communication and approaching to 5G. Towards the development in digital world, multicarrier modulation has predominantly ruled the wireless communications. Today, the utmost challenge posed by the next generation networks is the loss in spectral efficiency of wireless systems. There is scarcity of available resources and they even expensive since there are demands for larger bandwidth spectrum to accommodate the huge data rate requirement for growing multimedia applications along with the number of subscribers. MIMO-OFDM and its multiple access versions such as OFDMA are considered as spectrally efficient versions of OFDM systems so that the needs for present and future are met.

The filter bank multicarrier systems with orthogonal quadrature amplitude modulation (FBMC/OQAM) are potent enough to meet the technology demands for 5G by replacing the existing cyclic prefix based multicarrier scheme like CP-OFDM. Filter Bank Multicarrier System is a technique based on the prototype filters being designed for the transmitting as well as for the receiving end. The filter banks are represented as P_T and P_R for the transmitter and receiver respectively. The subcarrier signals are synthesized at the transmitter by the Synthesis Filter Bank and analysed at the receiver with the help of Analysis Filter Bank. Filter Banks prove to be an acquired form of sub band processing [13] of multicarrier systems after the CP based MIMO OFDM. The data is transmitted in the form of parallel data streams with the help of the modulated filter-banks. The (OQAM)-FBMC is implemented by employing the pulse shaping filters on each subcarrier and having supple waveforms, resulting in enhanced spectral confinement and hence making it capable to meet the greater requirements to be most suitable for fifth generation. Also, various European projects have been set into motion in order to surmount the hinderances occurred in OFDM to meet 5G demands, such as “mobile and wireless communications enablers for 2020 information society” (METIS) [39], “flexible air interface for scalable service delivery within wireless communication networks of the 5th generation” (FANTASTIC5G) [40], “enhanced multi-carrier techniques for professional ad-hoc and cell-based communications” (EMPHATIC) [41], and “5th generation non-orthogonal waveforms for asynchronous signalling” (5GNOW) [4]. Different modulation schemes are proposed, including Generalized frequency division multiplexing (GFDM), universal filtered multi-carrier (UFMC) and filter bank multi-carrier (FBMC). Choosing from these multicarrier schemes , FBMC tops the list to be most aspiring for 5G .

FBMC is considered to have its roots for a potent multicarrier technique even before the introduction of OFDM. In around 1960's, this technique came to be proposed by Chang, who came up with the idea for processing and signalling a parallel PAM modulated data stream through vestigial side band modulated filter banks which were overlapped [39]. For the transmission based on the Quadrature Amplitude modulated symbols, the research was carried out by Saltzberg [44]. An efficient implementation of filters was proposed by Hiroshaki [44] in 1980's, leading to the introduction of the polyphase implementation of Saltzberg Method. Saltzberg proposed OFDM based on Orthogonal-QAM or OQAM based OFDM, this method was called Staggered modulated multitone (SMT).

3.2 OVERVIEW OF OFDM

The OFDM is a predominant and widespread technology a back to multicarrier communication. The basic principle governed by multicarrier modulations is dissevering and mapping the input bit stream into various sub streams through different channels centred at different subcarrier frequencies. The frequencies cannot be retrieved at the receiver because of the orthogonality in the subcarriers is attained due to the minimal spacing between them, enabling compact usage of spectrum. The OFDM system implementation incorporates the transmission of a signal having wider bandwidth with many narrowband signals. The multipath delay spread engenders the inter symbol interference (ISI), the chances for its occurrence reduces because of the increase in symbol duration for lower rate parallel subcarrier. The narrow band signals in OFDM are prone to ISI and Frequency selective fading. It is observed that the bandwidth requirement for OFDM systems is remarkably low as compared to the traditional FDM systems. The efficient use of available resources (spectrum) is ensured by the carriers which are non-interfering in nature. It is kept in mind that corresponding to every subchannel the bandwidth is lower in comparison to that of the coherence bandwidth of the channel. So, the subchannels count, N is considered to significantly large. Efficient utilization of the resources is done during the OFDM operation, for there is overlapping with minimum carrier spacing which is carefully designed so that orthogonality between subcarriers is maintained. A pair of IFFT and FFT are incorporated at the transmitter as well as at the receiver respectively, for analysis of the signal in time and frequency domain. The block diagram for OFDM is depicted in figure.3.1. The OFDM modulated signal can be scripted as:

$$i(t) = \sum_{m=-\infty}^{+\infty} \sum_{n=0}^{N-1} c_{m,n} f(t - mT) e^{j2\pi n/T(t-mT)} \tag{3.1}$$

where T is denoted by OFDM symbol period, $f(t)$ is the rectangular window, $c_{m,n}$ is the complex symbol at mT instant.

3.2.1 Fundamental principles of OFDM

- The implementation of IFFT/FFT pairs at the Transmitter and Receiver
- Encoding and Interleaving
- The concept of Cyclic Prefix

The block diagram shows the step by step processing of the signal for the exploration of OFDM Systems. The source data is transmitted after processing it with Modulation (BPSK, QPSK, QAM).

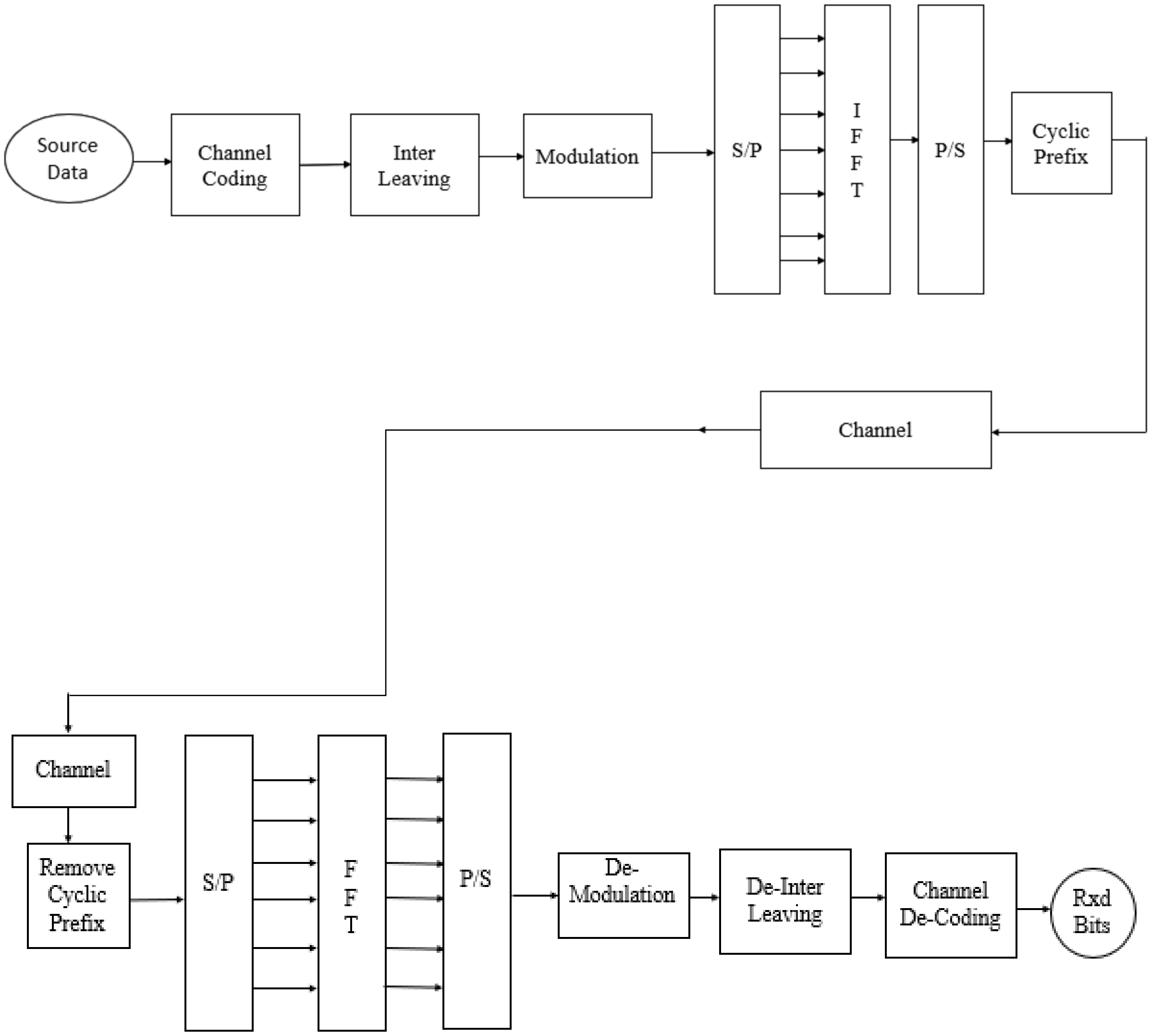

Figure 3.1. General Block diagram OFDM Transmitter and Receiver

3.2.1.1 Need for Fourier Transforms

To reduce the implementation complexity, the Discrete Fourier Transforms and Inverse Discrete Fourier Transforms are set up at the Transmitter and at the Receiver respectively. The fundamental idea is to convert the time domain signal to frequency domain and vice versa.

3.2.1.2 Encoding and Interleaving

The Channel coding is carried out at the transmitter to increase the system reliability by minimising the Bit Error Rate (BER) for a giver SNR value. With the objective that the data is transmitted error free, some coded bits are incorporated with the information to be transmitted, thereby reducing effective throughput. The process of interleaving facilitates the contents of the information are not lost and if some data gets missing during transmission, it can be recovered with little conjecture.

3.2.1.3 The concept of Cyclic Prefix

The introduction of CP in the OFDM symbols, i.e. by appending the tail part of the signal from the ending and merging it at the head end (beginning) for the signal to be transmitted is done in process of CP insertion. It is intended to permit the settling of multipath signals before the arrival of main data. The CP length is equal to the Guard Interval and usually predetermined. The standard length being 1/4 or 1/8 part of the transmitted signal. The effectivity of the cyclic prefix insertion is achieved when its length is equal to the length of multipath channel. The periodicity of the transmitted signal is due to the effect of Cyclic Prefix [53]. While, the CP inserted at the transmitter gets discarded at the Receiver, the CP is used as a guard interval that al fulfilled the purpose for the elimination of Inter Symbol Interference from the previous symbol.

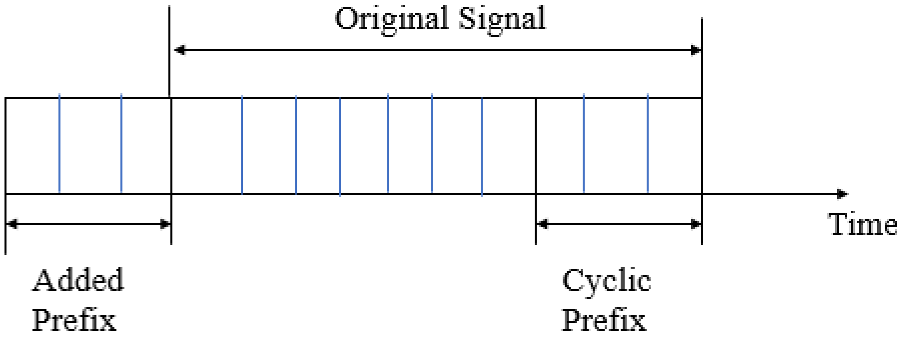

Figure 3.2. Introduction of CP in the original symbol

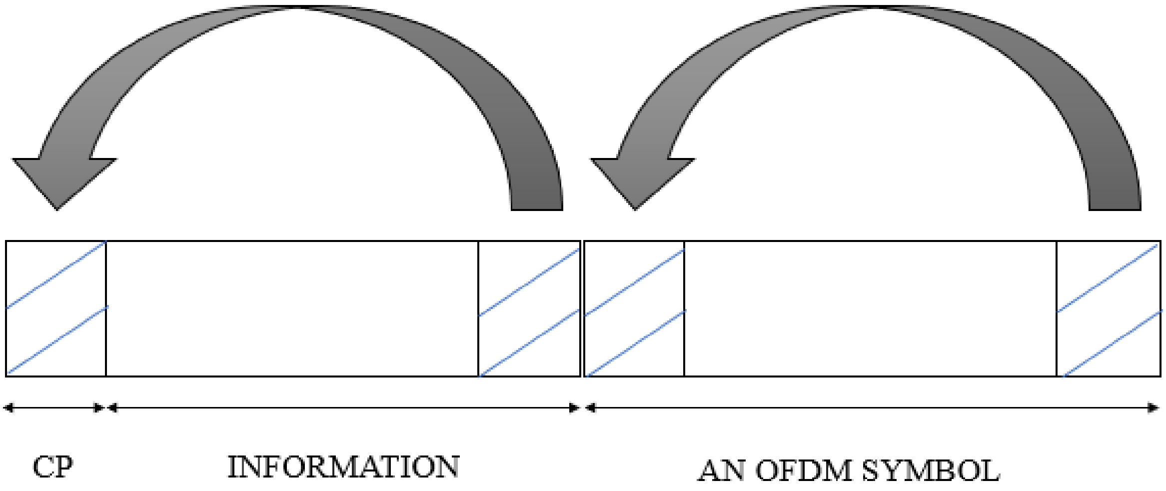

Figure 3.3. Process of CP Insertion

The circular convolution modelling for linearly convolved frequency-selective multipath channel is obtained as a consequence of repeating the CP at the end of symbol. By following this approach, it has led to the processing for simple frequency domain. The orthogonality of the adjacent subcarriers is preserved due to the introduction of Cyclic Prefix in OFDM systems for a multipath environment. In order to avoid the Inter Symbol Interference (ISI), it must satisfy the condition, $T_{Guard} > T_{max.}$

where T_{Guard} represents the length of the CP and $T_{max.}$ refers to the maximum delay spread. At a particular instant, when a signal in OFDM system gets transmitted with the CP insertion, the length of signal is $T + T_{Guard}$, where T represents the original length cycle for FFT Transform. To allow the mitigation of channel delay spread, a guard interval, either a CP or a Suffix is appended in the original transmitted signal. The length of the cyclic prefix to be appended is kept equal to that of guard interval. There is loss in power transmitted due to the transmission of redundant guard-interval (GI).

The cyclic prefix insertion is performed to avoid the delay spread in multiple path channels, reducing the interference in in frequency selective channels. However, the spectral efficiency of the OFDM signal is lost because of CP insertion. Also, some issues occur in synchronization of frequencies and sensitive to Doppler Shifts. The occurrence of ICI is because of the carrier frequency offset (CFO) in wireless domain system networks that emerges due to the mobility of the source at the transmitter end and the destination at the receiver end, thus making them prone to ICI.Also, there is doppler shift caused by the mobility of users, being the source of CFO.

Fading in multiple paths in wireless domain has been an obstacle for multicarrier modulation. Inter Symbol Interference in the wireless channel is caused as a consequence of multipath fading prevalent in wireless domain during multicarrier transmissions. The delay spread is directly proportional to the ISI in the channel and ISI being inversely proportional to the symbol duration. In order to decrease the ISI, the symbol period can be increased, but the data rate gets reduced. The upshot of ISI can be reduced by a factor N through performing the multiplexing of a data stream into N parallel sub streams, each having a slower rate by a factor of N in MCM. At the transmitter, the subcarriers fed parallel to the set of N modulators are modulated and added together. While, the N streams of symbols are separated and demultiplexed at greater rate stream of symbols at the receiver. Due to the well localisation of FBMC waveforms in time and frequency, the robustness of channel in time and frequency spreading gives a stronger point in its favour.

Larger sidelobes in frequency domain were obtained while using the rectangular impulse response prototype filters, thereby leading to unwanted magnitude response. This is due to the fact that the sinc pulses have larger sidelobes and the Inverse Fourier Transform of a sinc function is a rectangular pulse. [45] The increased side lobes, in turn causes interference in adjacent channels resulting in spectral leakage. Measures leading to reduce the spectral leakage factor will making the future communication systems more spectrally efficient. Filter bank multicarrier systems are designed for relatively greater Bandwidth efficiency, due to which the data symbols adjacent to each other overlap. An issue demands serious attention is the High Peak to average power ratio (PAPR), which has been an intrinsic drawback for all the multicarrier systems leading to power loss and the system efficiency gets reduced manifold.

3.3 INTRODUCTION TO FBMC

The FBMC systems can be distinguished from OFDM based on the prototype filter employed. A rectangular pulse shaped filter was used in OFDM while in FBMC, various robust filters are employed to serve the filtering purpose.

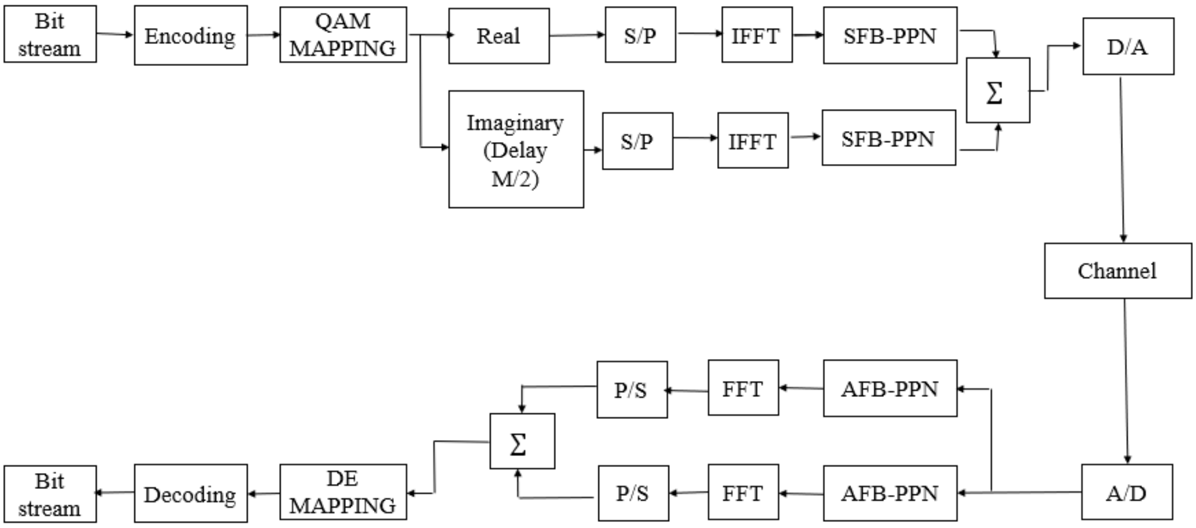

Figure 3.4. General block diagram of FBMC systems

The idea of filter banks can be drawn as an extension of the direct Fast Fourier Transform. The PPN-FFT technique is followed to implement the Filter Banks, that hold the size of FFT adding a set of digital filters. The parallel transmission and reception can be explained by the figure 3.4 and figure 3.5 respectively.

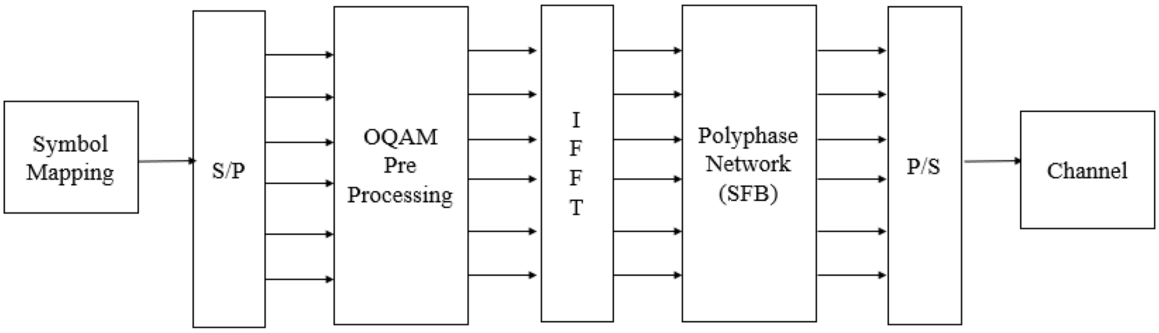

Figure 3.5. General Block diagram FBMC Transmitter

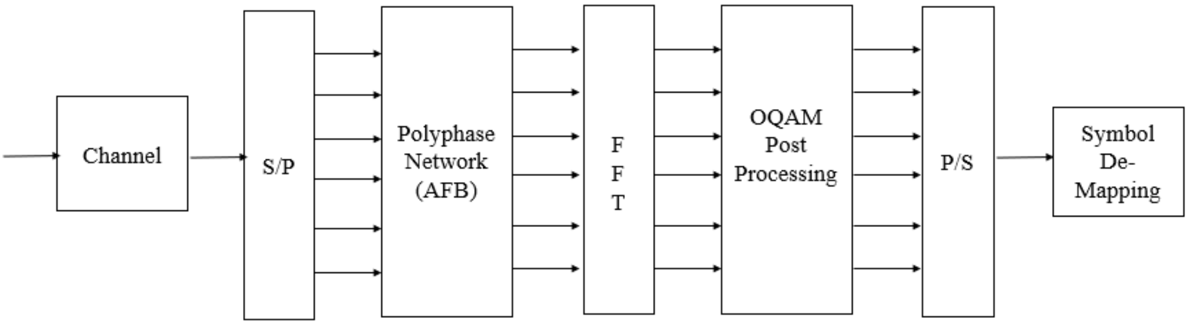

Figure 3.6. General Block diagram FBMC Receiver

3.3.1 FBMC principle

The basic configuration forming the basis of the FBMC -OQAM systems is the transmultiplexer. The transformation of time division multiplexed signal into frequency division multiplexed version and vice versa is carried out in the Transmultiplxer. Transmultiplexers can be termed as ‘Filter Bank Transmultiplxer’.

A multicarrier system consisting of filter banks each on the transmitter as well as the receiver side, known as Synthesis and Analysis filter banks respectively is called as transmultiplexer. The input time domain multiplexed signal is fed to the transmitting side of the transmultiplexer, which is divided into its different branches. The images of compressed spectrum of inputs will be obtained by up sampling with a factor M, for each branch’s values, as depicted in figure 3.7.

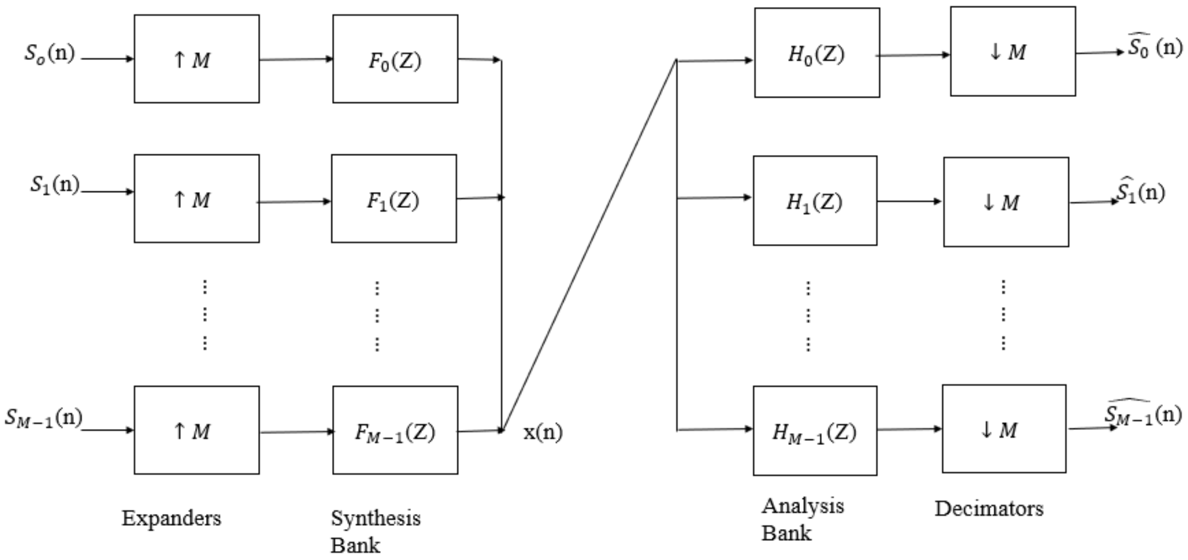

Figure 3.7. Transmultiplexer Configuration

The synthesis filter, employed at the transmitter performs filtering of the compressed components of the spectrum incurred from all the images which are further combined to form the transmitted signal. Hence, the input TDM signal gets converted to the FDM signal at the output of transmitting antennae. Now, the task of handling the combined input spectrum is done by the analysis filter at the Receiver. Breaking of the input stream into smaller streams with the help of predesigned analysis filters is carried out by down sampling by same factor and then expanding it, in order that the original fed input signal is recovered. This, in turn helps to obtain the initial TDM signal after the filter processing.

3.3.2 Sub band systems

A sub band system referred to as a SISO system i.e. single input single output system. Here, the set-up of filter banks is reversed i.e. the AFB is employed at the transmitting end and SFB at the receiver. The analysis filter bank divides the input into different branches. Each filter is centred at different frequencies and different components of input signal are processed. Then, the components undergo down sampling and the signals are coded and transmitted. At the receiver, the original sample rate is reconstructed and the received signals are up sampled which leads to the formation of images of signal. The images are then done away with by the bank of filters at the receiver (SFB) and thus adding the signals to get the output of original signal [48]. So, the conversion from FDM format to TDM format and further into FDM, is the job performed by the Sub band systems. It can be explained through the figure 3.8.

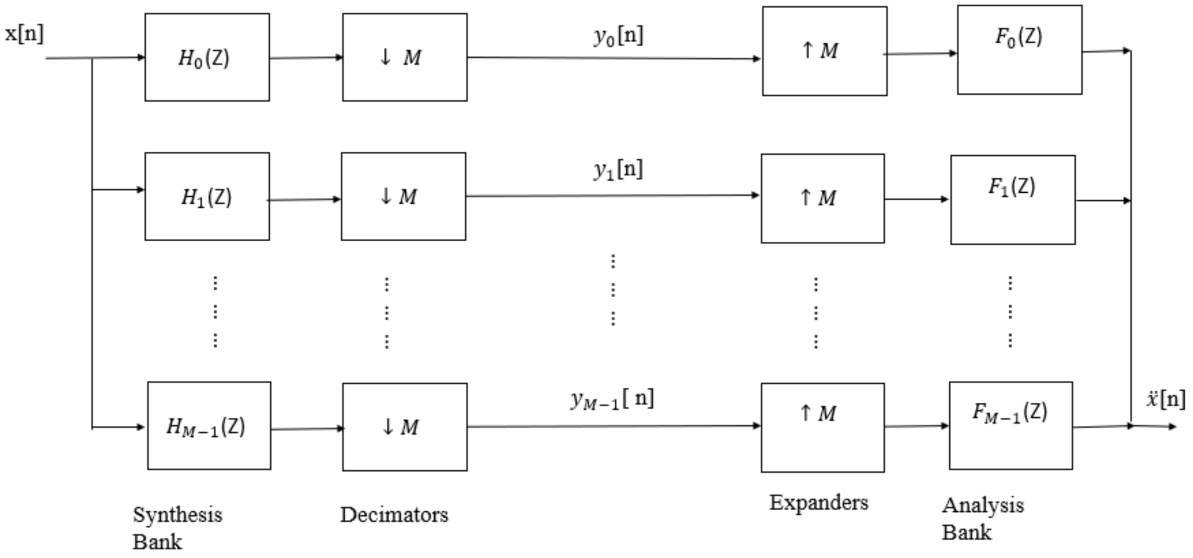

Figure 3.8. Sub band system diagram

3.4 FBMC-OQAM SYSTEM

The FBMC systems constitute of a bank of filters at the transmitting and receiving end. In subcarriers to ensure that the out of band radiation occurred is minimum, a prototype filter is considered which executes the separation of symbols. The shifted versions of the PHYDYAS filter in terms of phase and frequency are considered. With the advanced prototype filter design incorporated in FBMC, there is better localization for subcarriers in time and frequency.

Based on the type of transmission the FBMC signals can be categorised into two classes. When the real valued signal is to be transmitted, pulse amplitude modulation (PAM) is employed while for complex valued signal quadrature amplitude modulation (QAM) is utilised. Generation of FBMC Signals can be done by following three methods i.e. staggered modulated multitone (SMT), cosine modulated multitone (CMT), filtered multitone (FMT).

- Staggered Modulated multitone (SMT): This process is called as Multicarrier with Offset QAM. The carrier spacing is isochronal to the symbol rate and the subcarrier bands having minimum spacing with maximum overlapping.
- Cosine Modulated Multitone (CMT): There is maximum overlapping with subcarriers being spaced minimally. It utilizes the Pulse Amplitude Modulation (PAM) symbols accompanied with vestigial sideband modulation. The spacing between carriers is half the symbol rate.
- Filtered Multitone (FMT): There is no overlap between the subcarriers. The symbols are modulated using quadrature amplitude modulation. The separation between subcarrier bands is done by guard bands.

The implementation of different methods examines the effectiveness for bandwidth utilization. According to the researches, both SMT and CMT achieved bandwidth efficiency in the maximum amount while FMT has less bandwidth efficiency.

Generation of FBMC signals using Offset Quadrature Modulation (OQAM) is carried out by staggered modulated multitone (SMT). The filter is so chosen such that the same filter can be employed at the receiver as well as the transmitter for multicarrier systems. The root Nyquist filter for pulse shaping with symmetric impulse response is used and a delay of half symbol period is given to the QAM symbol components which have the same phase (in-phase) and the components having quadrature phase(out-of-phase). Due to the half symbol delay, it gets easier to achieve the arrangement for adjacent subcarriers which are separated by an interval equivalent to the baud rate length. The information symbols can still be retrieved and are done away with Inter-Symbol-Interference (ISI) and Inter-Carrier-Interference (ICI). Accordingly, these filtering systems (FBMC) seem to more promising candidate in terms of efficiency in bandwidth than the pre-existent OFDM systems. Implementing according to the SMT method, N data streams are parallelly fed as inputs to N filters [3].

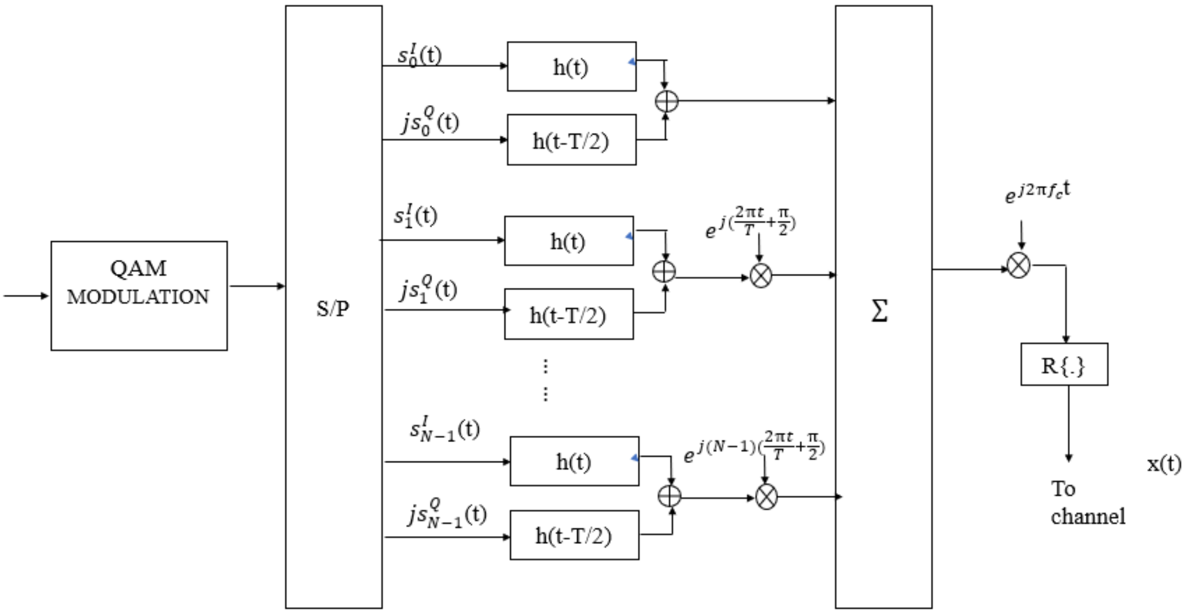

Figure 3.9. Block diagram SMT Transmitter

The time staggering by half symbol duration $\frac{T}{2}$ is applied to the in phase and quadrature phase components. The filtered outputs are further modulated with N subcarriers having frequency separation of $\frac{1}{T}$.

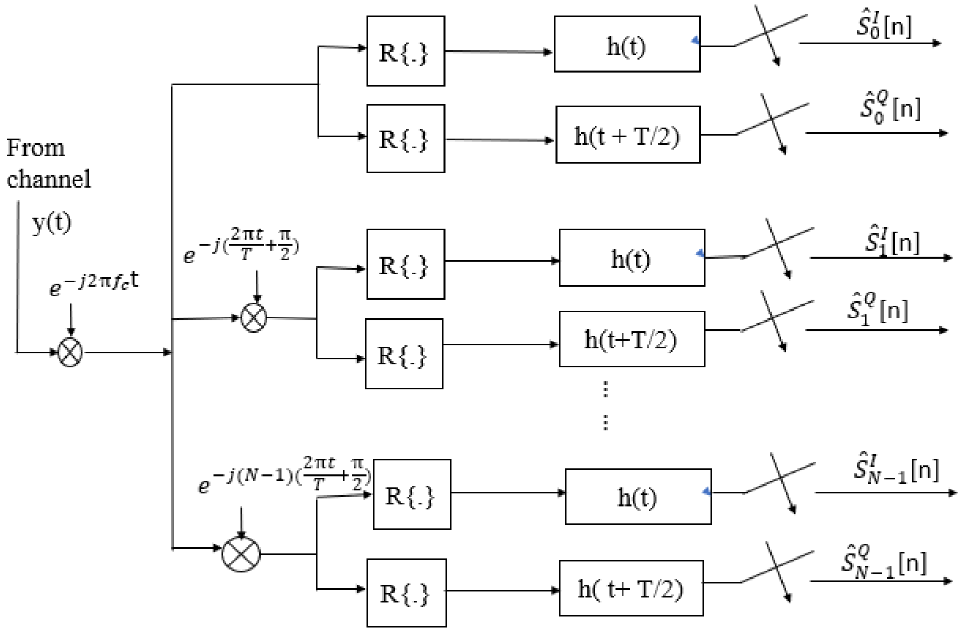

Figure 3.10. Block diagram SMT Receiver

Let $x(t)$ be the complex symbol at the transmitter, given by

$$x(t) = \sum_{m=0}^{N-1} \sum_{l=-\infty}^{\infty} s_m(l) h(t-nT) e^{\frac{j\pi}{2T(t-lT)}} e^{jm\left(\frac{2\pi t}{T}+\frac{\pi}{2}\right)} \tag{3.3}$$

Here, the in-phase components are shown as $s_k^I[t]$ and $s_k^Q[t]$ represents the quadrature phase components of k^{th} subcarrier and n^{th} symbol.

$$s_k^Q[t] = \sum_k s_k^Q[n]\, \delta(t-nT) \tag{3.4}$$

The delta function is denoted by $\delta(t)$.The SMT modulated complex signal can be expressed as:

$$x(t) = \sum_{m=0}^{N-1} \sum_{l=-\infty}^{\infty} s_m^I[l] h(t-nT) + js_m^Q[l]\, h(t-lT-\frac{T}{2}))\, e^{jm(\frac{2\pi t}{T}+\frac{\pi}{2})} \tag{3.5}$$

The major blocks responsible for its working are the OQAM pre-processing, synthesis-filter-bank (SFB), analysis-filter-bank (AFB) and OQAM post-processing.

The number of subcarriers, NN of the FBMC-QAM is assumed to be even ($NN = 2M$, where M being a positive integer). Initially, at the transmitter, the OQAM modulator processes input data stream.

$$A_m = \left[a_{m,1}\, , a_{m,2}, \ldots\ldots a_{m,NN}\right] \tag{3.6}$$

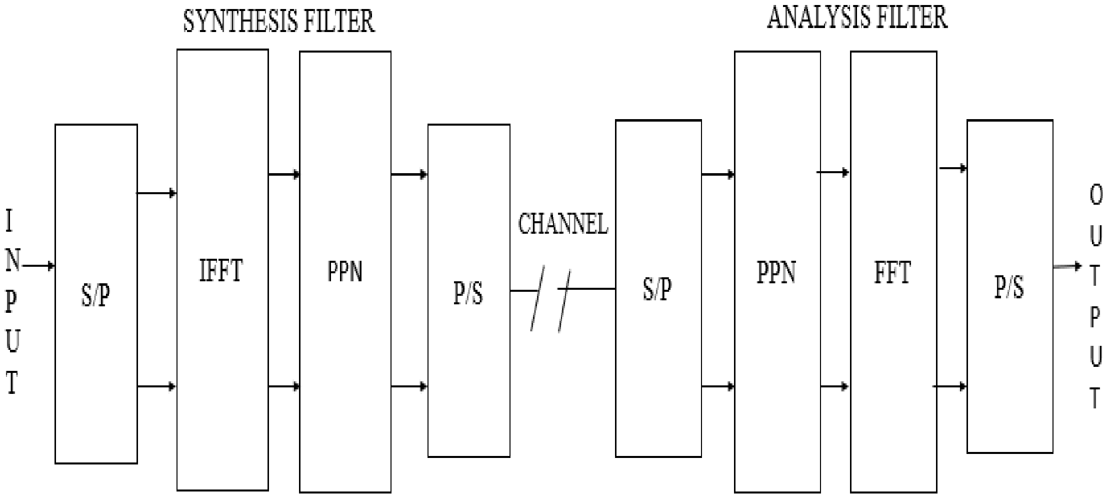

Figure 3.11. Block diagram FBMC

There is time staggering by $\frac{T}{2}$ in the real and imaginary parts of complex symbol, where T denotes the symbol period. It is then fed to the IFFT block and further processed. The PHYDAS Prototype filter is taken into consideration both at the transmitter as well as the receiver and the impulse response for this filter, h(t). It is noted that the SFB and AFB pairs are implemented expeditiously using FFT and IFFT having size M, aided by polyphase filtering structures. Then the FFT is calculated along with the QAM demodulation being carried out to obtain the received data. The system model has been depicted in the block diagram given in Figure 3.14. The mth FBMC/OQAM data block signal in time domain is expressed as:

$$S_m(t) = \sum_{n=1}^{NN} a_{m,n}\, h_{m,n}(t) \tag{3.7}$$

$$S_m(t) = \sum_{n=1}^{NN}\{R\{a_{m,n}\}h(t - mT) + jI\{a_{m,n}\}h(t - mT - \tfrac{T}{2})\}e^{j\emptyset\, m,n} \tag{3.8}$$

$$mT \le t < T(m + \beta + 1/2) \tag{3.9}$$

where $a_{m,n}$ denotes the mth QAM symbol and n^{th} subcarrier, β represents the overlapping factor, $\emptyset_{m,n}$ is the additional phase term, equivalent to

$$\emptyset_{m,n} = n\left(\frac{2\pi t}{T} + \frac{\pi}{2}\right) \tag{3.10}$$

Let $S_m(t)$ be individual data block, that consists of M consecutive blocks. The overall transmitting signal given as:

$$S(t) = \sum_{m=1}^{M} S_m(t), 0 \le t \le T(M + \beta - 1/2) \tag{3.11}$$

3.4.1 OQAM Mapping

3.4.1.1 OQAM Pre-processing

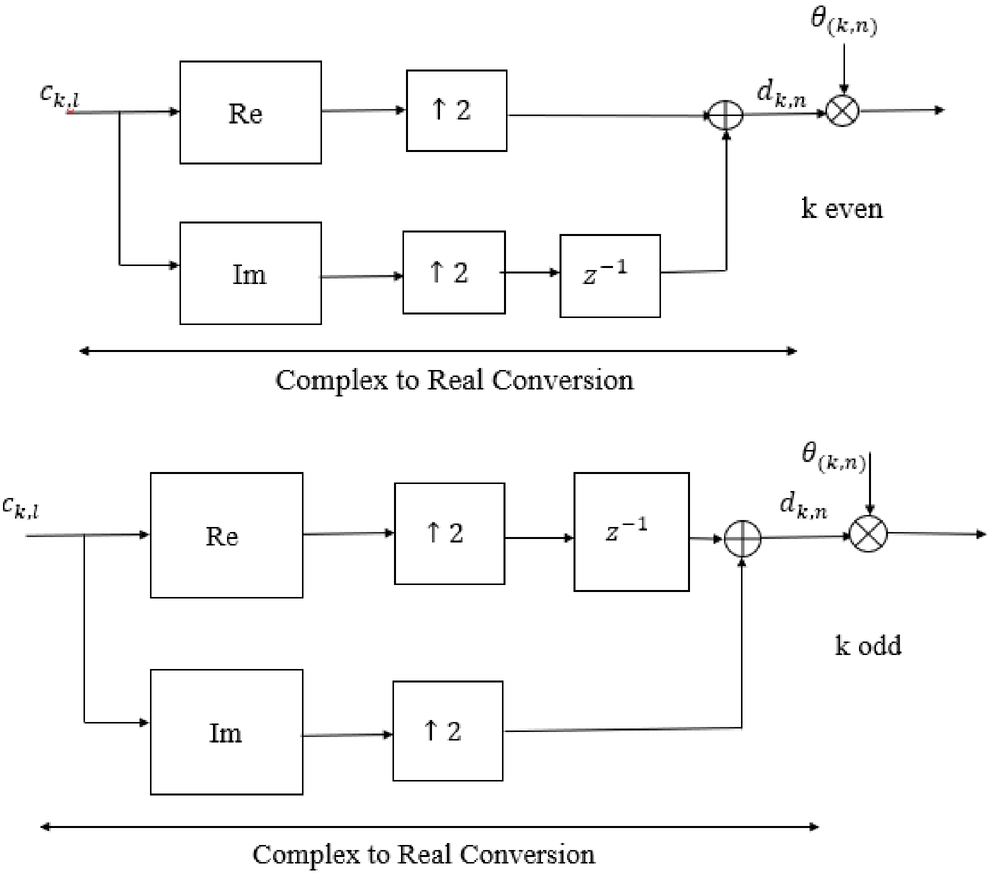

Figure 3.12. OQAM Pre Processing

The OQAM Pre/Post processing phenomenon is necessary to produce FBMC signal by SMT method [9]. The complex to real conversion is carried out in the OQAM Preprocessing.The QAM modulated signal gets transformed into OQAM signal. The real and complex components of the symbol at the input $c_{k,l}$ is divided into two sub parts, $d_{k,2l}$ and $d_{k,2l+1}$ as shown in Figure 3.12.

There is different conversion for even and odd number of subcarriers. The sampling rate is increased by a factor of 2 on performing the complex to real conversion. Next, the multiplication by a sequence $\theta_{k,n}$ is done to ensure interference free transmission between adjacent subchannels.

3.4.1.1 OQAM Post-processing

During the OQAM Post processing, the input data stream is initially fed to the multiplier which performs the multiplication of the input with the sequence $\theta_{k,n}^{*}$ and only the real part is taken into consideration.

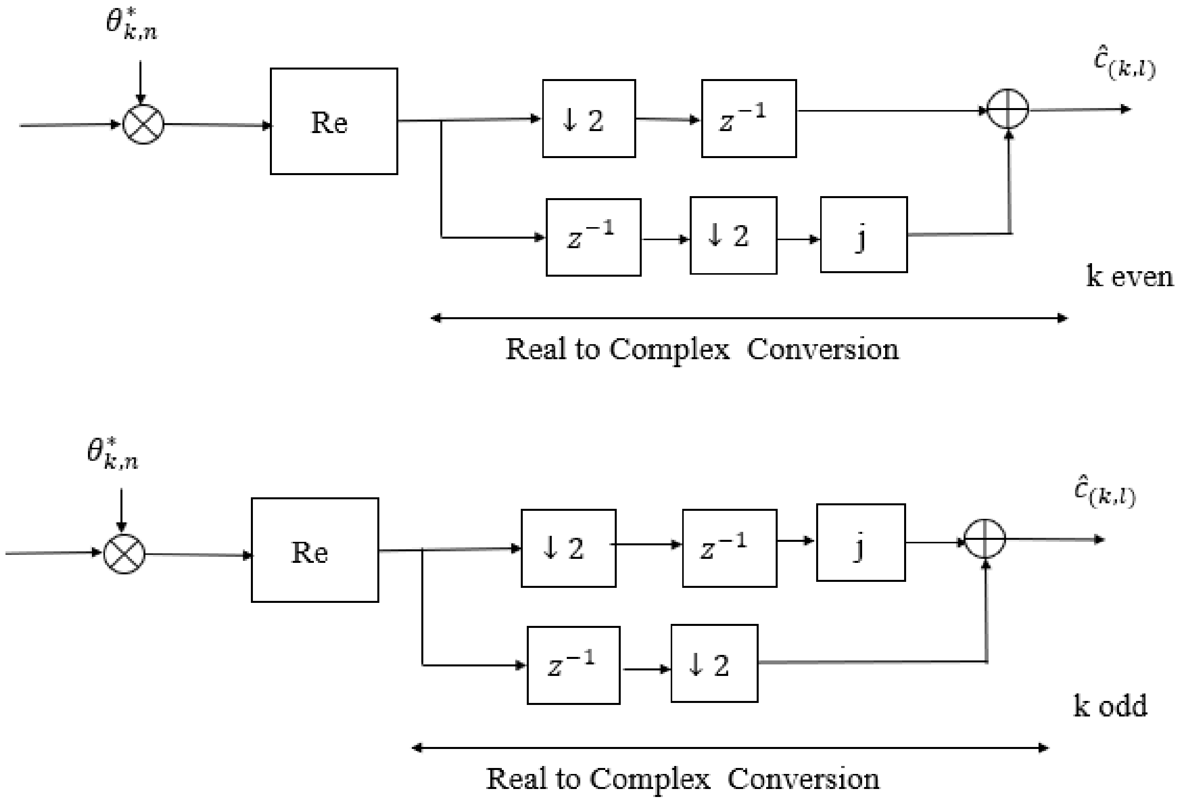

Figure 3.13. OQAM Post Processing

The figure 3.13 explains the transformation of real to complex is done, resulting in two complex symbols which are successive. A real valued symbol $\hat{c}_{k,n}$ is obtained after the conversion. In this case the rate for sampling gets diminished by 2. These conversions depict QAM to OQAM and vice versa transitions required for the signal generation for FBMC.

3.5 SYNTHESIS AND ANALYSIS FILTER BANKS

After the OQAM pre-processing, the modulated symbols are fed as M inputs for up sampling which are up sampled by $\frac{M}{2}$. Now the symbols are filtered through the synthesis-filter-bank and the filtered outputs are combined for transmission. The transmitted signal travels through the channel to reach the receiver. The receiver bank of filters, called the AFB performs the filtering operation on the signal again and it is down sampled by a factor of $\frac{M}{2}$ .The figure 3.14 corresponds to detailed processing of blocks for FBMC-OQAM systems.

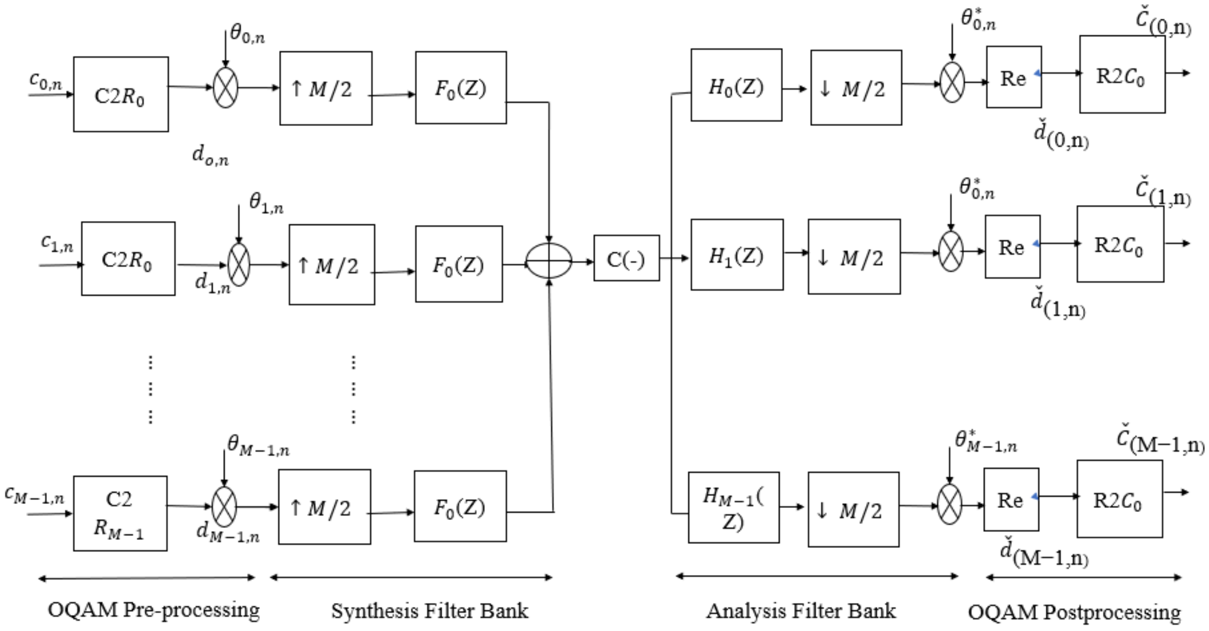

Figure 3.14. The Filter bank structure diagram

The Isotropic Orthogonal Transform Algorithm (IOTA) [46] and the PHYDYAS filters are predominantly proposed as IFFT windows. It is suggested that PHYDYAS filter performs better than the IOTA. Due to the larger length of IFFT Window in time domain in FBMC-OQAM systems, it greatly differentiates it from the CP-OFDM. Consequently, the side lobes in the frequency domain in the FBMC-OQAM systems are minimized and hence its spectral leakage. Also, FBMC Modulation is tolerant towards carrier frequency offset (CFO) and have improved sampling frequency offset (SFO). The intention of employing FBMC systems with Offset Quadrature Amplitude Modulation is to induce signal regeneration. There is half symbol time duration shift between the real and imaginary i.e. In phase and Quadrature phase. Before applying the FFT block, each branch is phase shifted to their samples. After that, the time domain signal in the Imaginary branch is delayed by half symbol duration. Further, the window is being applied to the branches and the outcomes are combined. The procedural steps in reverse order are being practiced at the Receiver. The frame obtained at the receiving end is segregated into two branches and are fed to the shifted versions of windows. Followed by the FFT application, phase recovery is carried out. The branches are merged again before data recovery [4].

3.5.1 Prototype Filter Design – PHYDYAS

The measure of interference between the subchannels is determined by the prototype filter used for filtering process. The digitization of analog signals is chiefly based upon the Nyquist criterion. The preferred filter to be designed is Nyquist filter, considering the frequency coefficients and satisfying the symmetry conditions being imposed. The filters should ensure perfect reconstruction(PR) or near perfect reconstruction(NPR). For the development, European project in 5G communications providing dynamic spectrum access in physical layer, PHYDYAS [24] filter is considered. PHYDYAS Filter's localisation in frequency has surpassed one (rectangular) used in OFDM Systems. While in some works, the researchers have also regarded the Isotropic Orthogonal Transform Algorithm (IOTA) Filter as the prototype filter for designing of filtered multicarrier systems.

For the transmission phenomenon to take place, there is splitting of global Nyquist filter into two parts, such that both the transmitter and receiver can accommodate each half Nyquist filter. Subsequently, the squares of frequency coefficients satisfy the symmetry conditions. The samples incurred as result of the inverse Fourier transform are KM, where K is referred to as the overlapping factor and M denotes the number of samples for passband of each prototype filter. Here, the filter length is represented as $Lp = KM - 1$.For different values of K, ($K = 2,3,4$) the frequency coefficients for Half Nyquist can be obtained and tabulated in the following table.

Table 3.1. Frequency domain prototype filter coefficients

K	H_0	H_1	H_2	H_3	σ^2
2	1	$\sqrt{2}/2$	-	-	-35
3	1	0.911438	0.411438		-44
4	1	0.971960	$\sqrt{2}/2$		-65

The inverse Fourier transform of the pulse frequency response gives the impulse response for the filter that is represented by $h(t)$,

$$h(t) = \begin{cases} \frac{1}{\sqrt{A}}\left[1 + 2\sum_{k=1}^{K-1}(-1)^k H_k \cos\left(\frac{2\pi kt}{KT}\right)\right] \; \mathrm{t} \in [0, kT] \\ \mathrm{h(t)} = 0 \quad \mathrm{elsewhere} \end{cases} \tag{3.12}$$

where A represents the Normalization constant, given by,

$$A = KT[1 + 2\ \sum_{k=1}^{K-1} H_k^2] \tag{3.13}$$

The filter bank structure can be acquired from the prototype filter by shifting the frequencies for all the subcarriers. The filter coefficients are multiplied by the value $e^{j2\pi ki/M}$ to obtain the filter having index k.The “background noise” power has emerged out as an essential parameter for the design of prototype filter, because the spectrum sensing and bit loading are greatly impacted. The residual interference power beyond the contiguous subchannels owing to the non-orthogonality of the subcarriers. Different values of σ^2 are calculated for the varying values of the overlapping factors K, as shown in the Table 3.1.

3.5.2 IOTA Filter

As per the Heisenberg-Gabor uncertainty principle [49], the Gaussian pulse $g(t) = e^{-\pi t^2}$ has the most well localized pulse shape in the time and frequency domain since no changes occur in it on application of Fourier transformation. Nevertheless, the real orthogonality conditions were not satisfied by this pulse. Subsequently, it was possible to achieve an orthogonalized pulse from a Gaussian pulse by the introduction of conversion algorithm [20], which resulted in the formation of IOTA Prototype function. The extended form of Gaussian function is known as IOTA prototype function. The equal localisation of the filter in time and frequency domains is because of the prototype function and its Fourier transform being indistinguishable. The remarkable time frequency localization exhibits its low sensitivity for time truncation than the square root raised cosine filter.

3.6 THE EFFECTUATION OF FILTER BANK USING FFT

To bring the filter bank scheme into effect, the figure3.15 described above can be considered for extending the IFFT and FFT to implement the system. As in the former OFDM Systems, each subcarrier modulated the input stream of data but here for the case of FBMC, the data stream gets modulated by $2K - 1$ subcarriers. The value of overlapping factor used is represented as K, and the size of FFT being KM for the generation of all requisite carriers. Initially, the filter coefficients (H_k)get multiplied by the data elements($d_i(mM)$) one by one. Each data element after being filtered by the filter coefficients is further operated with the IFFT operation, where the FFT with size $2K - 1$ inputs having indices $(i - 1)K + 1, \ldots\ldots, (i + 1)K - 1$. Basically, elements of data are dispensed over various inputs of IFFT and this data spreading is termed as “weighted frequency spreading”.

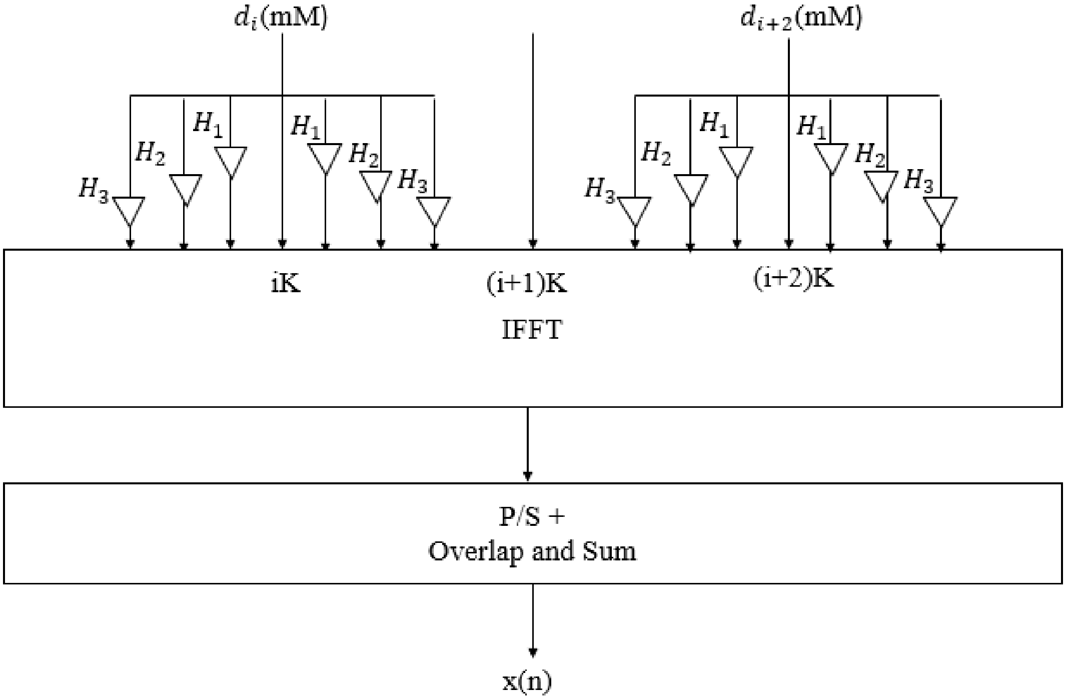

Figure 3.15. Implementation using “Weighted Frequency Spreading” at Transmitter

The figure 3.15 shows the effective way to spread the weighted frequency with $K = 4$.There is no overlapping between the indices i and $i + 2$ belonging to separate sub channels but it is observed that the channels having indices $i + 1$ have overlapping with the adjacent carriers i and $i + 2$.So, it becomes essential to uphold orthogonality amongst immediate subcarriers i and $i + 2$.This is achieved by feeding the $i + 1^{th}$ subcarrier to the imaginary IFFT inputs and real inputs for i and $i + 2$ or vice versa.

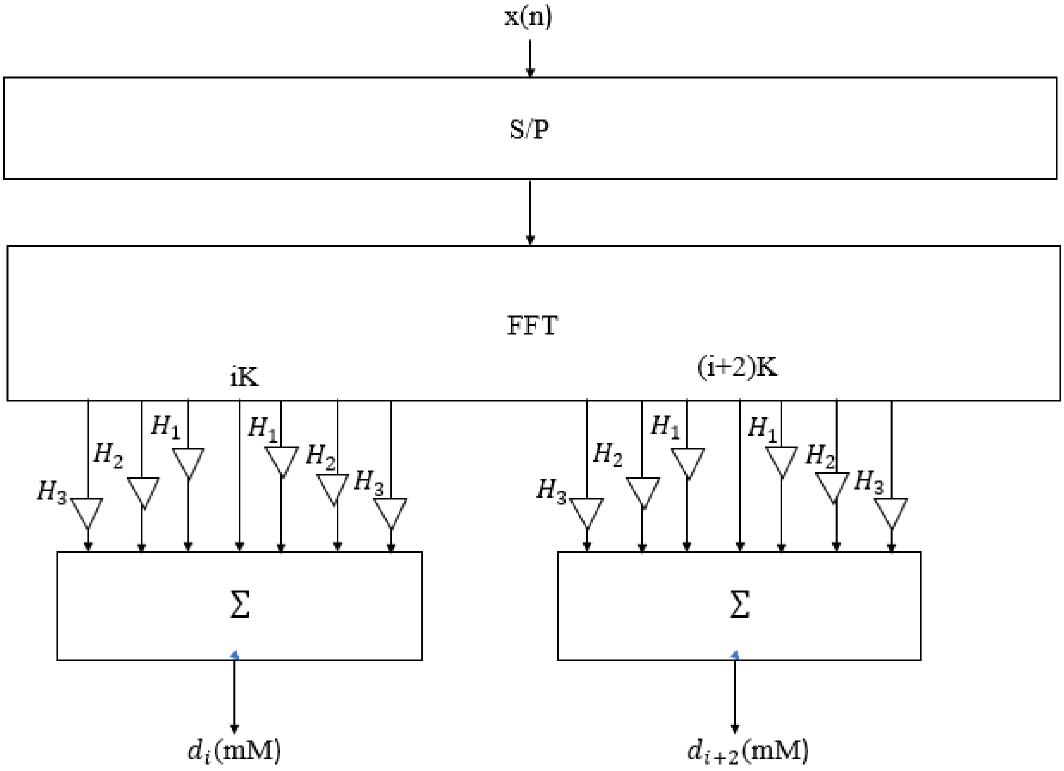

Figure 3.16. Implementation using "Weighted Frequency De-spreading" at Receiver

At the receiver, the extended FFT operation is being utilized. Overlapping occurs between input blocks of FFT.After the elements get treated with the FFT block, a weighted dispreading is carried out in order to recuperate the data elements. The receiver operation is performed as depicted in figure 3.16. The data recovery can be put into practice availing the Nyquist filter's property of frequency coefficients, given

$$\frac{1}{K}\sum_{k=-K+1}^{K-1}|H_k|^2 = 1 \tag{3.14}$$

3.7 FILTER BANK IMPLEMENTATION USING PPN-FFT

On discussions of previous method, it is seen that the complexity of the system is boosted due to the time domain overlapping in the IFFT outputs and FFT inputs. Also, the IFFT/FFT size has increased from K to KM. The polyphase Network structure is well suited to overcome the complexity.

In PPN method, the size of FFT is maintained as earlier value, i.e. M, in addition to some additional processing. The set of frequency coefficients for the prototype filter in the time domain are related to the input and output sequence values as expressed in the equation as follows:

$$y(n) = \sum_{i=0}^{L-1} h_i \, x(n-i) \tag{3.15}$$

Let the sequence of coefficients $h_i(0 \le i \le L-1)$ define the filter impulse response and the filter length is L. The frequency response for the filter with the sampling frequency value considered to be equal to one and is given by

$$H(f) = \sum_{i=0}^{L-1} h_i e^{-j2\pi i f} \tag{3.16}$$

The symmetrical linear phase filter coefficients. The delay for the filter is given by τ,which can be expressed as follows

$$\tau = \frac{L-1}{2} \tag{3.17}$$

Conventionally, for the filtering process to be carried out digitally in digital signal processing, the generalized frequency response is carefully weighed. The z transform is utilized for this purpose. The frequency response can be scripted as

$$H(Z) = \sum_{i=0}^{L-1} h_i Z^{-i} \tag{3.18}$$

Since the filter length is determined by $L = KM$. The Z transform equation can be written as in double summation because the coefficients of filter can be disintegrated into M number of sequences which are interleaved obtained from K coefficients, given by

$$H(Z) = \sum_{p=0}^{M-1} H_p(Z^M) \, Z^{-p} \tag{3.19}$$

$$H_p(Z^M) = \sum_{k=0}^{K-1} h_{kM+p} Z^{-kM} \tag{3.20}$$

Each filter element represented by $H_p(Z^M)$ is found to have the phase shifter frequency response. So, for the complete set, the implementation for polyphase network can be carried out. The generation filter bank at the transmitter is obtained by applying the frequency shift on the prototype-filter(PHYDYAS). After shifting the filter by the frequency factor, $\frac{1}{M}$, the frequency response is given by H(f) is

$$B_1(f) = H\left(f - \frac{1}{M}\right) = \sum_{i=0}^{L-1} h_i e^{-j2\pi i (f - \frac{1}{M})} \tag{3.21}$$

The global Z transfer function defined as

$$B_1(Z) = \sum_{i=0}^{L-1} h_i e^{j2\pi i/M} Z^{-i} \tag{3.22}$$

The decomposition of filter in a polyphase network is given as:

$$B_1(Z) = \sum_{p=0}^{M-1} e^{j2\pi p/M} Z^{-p} H_p(Z^M) \tag{3.23}$$

All the filtered outputs of the filter bank are added up and then the summed signal is transmitted for the implantation of filter banks. The functions $H_p(Z^M)$ remain unaltered by the shifts in frequency. A matrix equation is obtained by considering all the filters and the shifts in frequencies by multiples of $\frac{1}{M}$, by substituting $W = e^{-j2\pi/M}$

$$\begin{bmatrix} B_0(Z) \\ B_1(Z) \\ \cdot \\ \cdot \\ B_{M-1}(Z) \end{bmatrix} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & W^{-1} & & W^{-M+1} \\ & \vdots & \ddots & \vdots \\ 1 & W^{-M+1} & \cdots & W^{-(M-1)^2} \end{bmatrix} \begin{bmatrix} H_0(Z^M) \\ Z^{-1} H_1(Z^M) \\ \cdot \\ \cdot \\ Z^{-(M-1)} H_{M-1}(Z^M) \end{bmatrix}$$

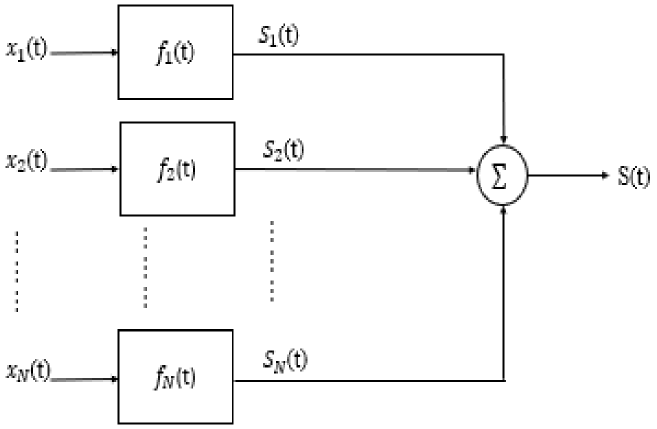

Figure 3.17. Synthesis Filter Bank (PPN)

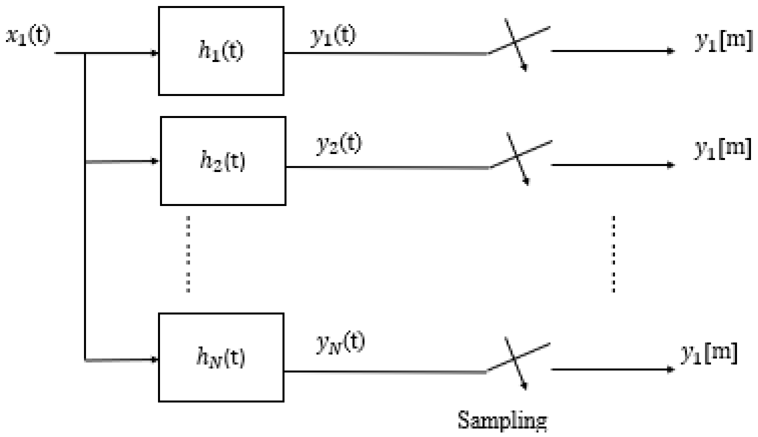

Figure 3.18. Analysis Filter Bank (PPN)

At the receiving end, the bank of filters (AFB) utilize the same schematic as that of the transmitter. Here the frequency gets shifted by the multiples of $\frac{1}{M}$ and the DFT operation is carried out on the sequence values. The signal corresponding to each sub channel is made to shift across the frequency origin and the outputs are fed to filters for filtering operation. The filtered elements obtained were seen to be unvarying for all the bank filters and the received signal is the aggregate of all signals of sub channels, so the processing applied was common followed by DFT which separates the signals. The transmission in filter banks based on the PPN-FFT [46] scheme is shown in the figure 3.17 and the reception is done using AFB PPN structure as depicted in figure 3.18.

3.8 OQAM MODULATION

When the subcarriers are distinguishable in FBMC Systems, the signals can be modulated by any of the modulation techniques. For the cases where there is exploitation of only even or odd indexed sub channels, overlapping is not noticed. So, the symbols can be QAM modulated. However, with the objective for the accomplishment of full speed, it is required to exploit the sub-channels and a particular modulation is taken up altogether so that the overlapped adjacent subchannels in frequency domain are matched. The cause of overlapping in adjacent symbols in FBMC-OQAM is due the duration of the impulse response for the filter, $h(t)$. The main lobe contains the energy predominately for the PHYDYAS filter. To get a better clarification for the symbols to be overlapped, it is important to acknowledge the FBMC-OQAM signal's mean power profile. The length of $h(t)$ is associated with the time dispersive nature, for there is an offset of $\frac{T}{2}$ between real and imaginary components for the modulated symbol. The overlapping structure for FBMC symbols can be visualised by figure 3.19.

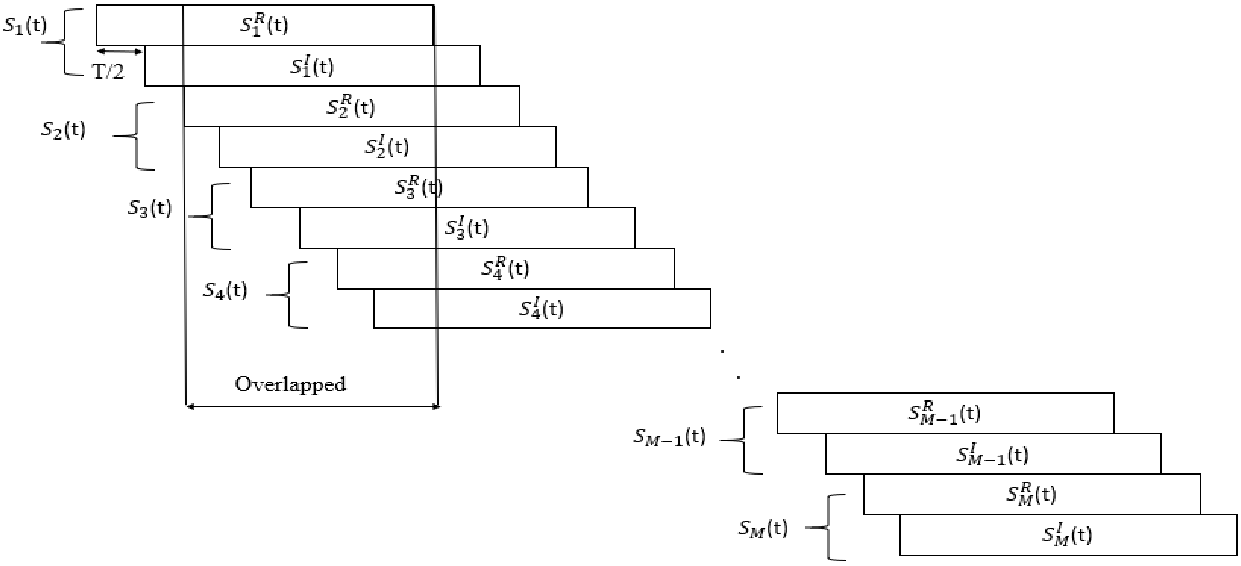

Figure 3.19. Overlapping in FBMC Symbols

The word ‘Offset’ in Offset Quadrature Amplitude Modulation is manifested by the half time period shift of subchannel spacing between the in phase and complex valued quadrature phase components of the generated symbol. The throughput rate is same as that for QAM systems for the latter day multicarrier systems, as it is put to use in OFDM systems but in FBMC the guard time interval is not there [46].

FBMC has legion benefits over the pre-existent multicarrier modulation techniques, but it still affected by high Peak to Average Power Ratio (PAPR). In every multicarrier system, there occurs a severe problem of high PAPR since the output symbol is calculated by coherent addition of all the modulated symbols on different subcarriers [52]. Even in CP based OFDM systems PAPR has been a shortcoming. In OFDM systems, a very large dynamic range of noise like amplitudes are displayed by the OFDM signal, which calls for the requirement of RF Amplifiers with high PAPR. The complexity of Analog to Digital (A/D) and D/A converters is enhanced as a result of high PAPR. This, in turn causes degradation in performance of power amplifiers and the OFDM systems efficiency is lowered.

3.9 PEAK TO AVERAGE POWER RATIO (PAPR)

During transmission, the summation of modulated subcarrier values may lead to a huge value as compared to sample’s average value, which causes a ‘peak’ in the output. When the sinusoids having zero phase difference between each other get added up lead to a significantly high peak power with regards to each signal’s power. When there are large number of variations in the amplitudes of the multipath signals transmitted, there is a need for non-linear power amplifiers. Therefore, power loss is more. The power value of peak, called peak power for a sinusoidal signal has an amplitude value equivalent to the maximum value for the envelope. This means that the PAPR is 0dB for an unmodulated signal and it has the Crest factor value equal to 3dB.The Crest factor for a signal proves to be an alternative to measure envelope variation. The -maximum signal value divided by the RMS signal value is termed as the Crest Factor. When the center frequency is comparatively higher than the bandwidth of the signal, there is 3dB difference between the Crest factor and PAP ratio is obtained.

It is defined as the ratio of the maximum power of the sample to the average power of the sample. In addition to this, high PAPR is resulted as an outcome when the different subcarriers are out of phase with each other [53].

As it is seen for OFDM systems that there is no overlapping between the adjacent symbol blocks, so PAPR was calculated for each symbol. Since the symbols in FBMC coincide partially, the PAPR can be defined as: Now dividing S(t) into M+β intervals, each interval having length T. The PAPR of each interval is expressed as:

$$PAPR(dB) = 10log_{10}(\frac{max_{iT\leq t\leq (i-1)T}|S(t)|^2}{E[|S(t)|^2]}) \tag{3.24}$$

where $i = 0, 1, M + \beta - 1, E[|S(t)|^2]$ represents the expectation value.

3.9.1 Effect of High PAPR

For any system designed for the communication process in wireless networks, the transmitter is equipped with linear power amplifiers. The working for linear power amplifier ensures the operating point lie in the linear region of operation. The high PAPR causes a shift in the operating point (Q point) position towards the saturation region, which results in peaks of signals being clipped and the generation of in band and out of band distortion. With the motive to keep the operating point (Q point) in linear region, the dynamic range for power amplifier needs to be augmented and hence cost of the power amplifier increases. Therefore, a trade-off is existing between efficiency and non-linearity [54]. This, in turn initiates and investigation regarding the techniques for minimizing PAPR in FBMC/OQAM systems.

3.9.2 PAPR Analysis using CCDF

Another useful parameter for the analysis of PAPR, is the probability of the PAPR value for a discrete signal to exceed beyond a threshold value $(PAPR_0)$ called the complementary cumulative density function (CCDF) [49]. For any random variable, say Z the probability of the event{Z≤z} can be defined by the CCDF of z. It can be regarded as the performance metric for the techniques leading to lowered PAPR. The CCDF can be reckoned as a predominant criterion for evaluating the execution of PAPR minimization. It is viable to express the distribution of PAPR values, employing the cumulative distribution function. It can be expressed as:

$$CCDF(PAPR_0) = \Pr(PAPR > PAPR_0) \tag{3.25}$$

Generally, for PAPR the CCDF can be codified as:

$$\Pr(PAPR > PAPR_0) = 1 - (1 - e^{-PAPR_0})^N \tag{3.26}$$

3.10 PAPR REDUCTION TECHNIQUES

Nowadays, reducing PAPR has become pivotal for the multicarrier systems. Various PAPR reduction techniques have been introduced so far for the MCM systems. The fundamental classification for minimization of PAPR can be done as follows:

- Distorted Signal Techniques
- Non-Distortion based Signal Techniques

The techniques causing power loss and distortion in the original signal after processing it with reduction technique, are termed as signal distortion techniques. These schemes are responsible for initiating the spectral regrowth phenomenon in multicarrier systems. This in turn, deteriorates the spectrum causing distorted signals.

While, if the PAPR is reduced using the reduction methods in order that the original signal remains unaffected and there occurs no loss of power, are called as Non-distorted signal techniques. Some of them are discussed below:

- Clipping and Filtering
- Companding
- Selected Mapping (SLM)
- Tone Reservation (TR)
- Tone Injection (TI)
- Active Constellation Extension (ACE)
- Partial Transmit Sequence (PTS)

3.10.1 Clipping and Filtering

Clipping is an elementary method to reduce the PAPR. According to principle of clipping, the amplitude of the signal at input gets confined to a preset value [54]. During transmission, a clipping level,x_c is defined for the clipping operation to take place. All the signals above the defined level get clipped off and the input signals peaks are minimized.
For a signal $x[n]$ to be transmitted, the $x_c[n]$ is its version in clipped form is expressed by:

$$x_c[n] = \begin{cases} -A, & x[n] \le -A \\ x[n], & |x[n]| < A \\ A, & x[n]\ A \end{cases} \tag{3.27}$$

where, A represents the clipping level. By performing the clipping technique, PAPR minimization is obtained but at the price of increased BER values, thereby producing in and out of band radiation in the signal. There occurs interference between adjacent channels due to the out of band radiation. It can be cut down by filtering the clipped signal. So, the signal gets distorted while at the time of transmission of the input signal after being projected to the clipping and filtering process [55].

3.10.2 Companding

Companding was introduced by Xianbin Wang, T. T. Tjhung and C. S. Ng [56]. For multicarrier systems, for multicarrier systems, non-linear companding is foremost choice for reduction of PAPR values due to less complexity and producing an effective BER.As the name itself suggests, so is its literal meaning. Companding means Compressing and then Expanding the signal. It is prevalent in digitization scenario since the dynamic ranges of digital to analog converts is enhanced. The higher peaks of the signals get attenuated by applying the companding function and the lower amplitude signals are amplified. The original signal is recovered at the receiver performing inverse companding operation.

The average power transmitted can be unaltered after the process of companding if the parameters are chosen properly. It has further classification types such as hyperbolic tangent (tanh), error function (erf), logarithmic function(log), Mu-law and A-law companding [59]. However, the μ law and A law Companding algorithms are dominantly favoured to perform this operation method causes the complexity in the system to be low.

3.10.2.1 μ law Companding

The function utilised in Companding at the transmitter end is given by

$$h(S_k) = \mathrm{u(Mu)}.\,\mathrm{sgn}\,(S_k)\,\frac{\ln(1+\mathrm{Mu}|S_k|)}{\ln(1+\mathrm{Mu})} \qquad (3.28)$$

At the transmitter side, the level of the signal companded is controlled by Mu ratio and the normalization constant is given by u(Mu). The reverse operation termed as the inverse companding can be expressed as

$$h'(r_k) = \frac{\mathrm{u(Mu)}^{-1}\,\mathrm{sgn}(r_k)((1+Mu)^{|r_k|}-1)}{\mathrm{Mu}} \qquad (3.29)$$

3.10.2.2 A law Companding

The companding function can be defined by the A law Compander as follows:

$$h(S_k) = k(A).\,sgn(S_k)\begin{cases} \frac{A|S_k|}{1+\ln(A)}\,, if\ |S_k| < |S_k|_{max}/A \\ 1+\frac{\ln(A|S_k|)}{1+ln(A)}\,, if\ |S_k| \geq |S_k|_{max}/A \end{cases} \qquad (3.30)$$

where $|S_k|$ is the absolute value of S_k,sgn(y)=sign of the input,

The level of companding enforced on the signal is controlled by A ratio. The decompading operation can be executed by the equation.

$$h'(r_k) = \mathrm{k(A)}^{-1} sgn(r_k)\begin{cases} \frac{|r_k|(1+\ln(A))}{A}, & |r_k| < \frac{|r_k|_{max}}{1+\ln(A)} \\ \frac{\exp(|r_k|(1+\ln(A))-1)}{A}, & |r_k| \geq \frac{|r_k|_{max}}{1+\ln(A)} \end{cases} \qquad (3.31)$$

where, k(A)represents the normalization constant value.

3.11 SIGNAL SCRAMBLING TECHNIQUES

On account of the superposition of multiple sub carriers in multicarrier schemes, high peaked power signals are emerged as a result. A single transmission process is exhibited by the bigeminal sub carriers holding same information and among them the best candidate is selected for a predefined threshold condition. The probability of occurrence for peak power signal can be reduced substantially.

The process of rotating the phase to achieve reduced PAPR can be characterised as a special case of multiple signal technology. The approach followed can greatly lower the probability of occurrence for higher power of peaks. The basic principle governed by the multicarrier systems to transmit multiple signal waveforms having same data from the initial blocks at the transmitter and then the waveform having least PAPR is chosen for transmission. The technique holds plenty of virtues which prove it to be a rewarding scheme with the objective to minimise the PAPR in the FBMC -OQAM systems. Despite the fact that, only the statistical characteristics get optimized, its benefits include lower redundancy and higher coding rates. There have been meritorious proposals for implementing the phase rotation schemes in multicarrier modulations (MCM). The reduction techniques SLM and PTS have captured the interests of researchers for High bandwidth can be utilized without loss of spectrum and renders less reduction in throughput.

3.11.1 Selected Mapping (SLM)

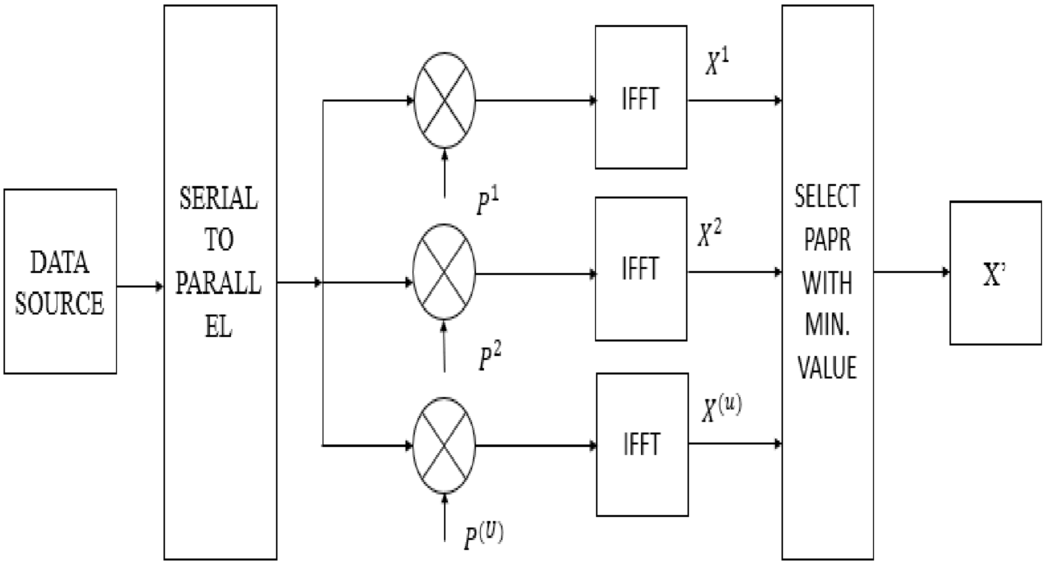

Figure 3.20. Block diagram SLM

The introduction to the scheme of selected mapping was given by Robert W. Bauml, Robert F.H. Fischer and Johannes B. Huber [60]. In SLM, there is generation of statistically independent frames from the original sequence, each of them having same information. Further, phase rotation is applied to each frame by U vectors each of length LN. The constellation posed by rotated symbols is identical to the input symbols [56]. The principle governing the Selected Mapping technique is based on the versatile allotment of data to transmit the signal [18]. After the alternative FBMC signals are attained from input, the one with minimum PAPR is transmitted. However, the data rate loss occurs and the system gets complex. The figure 3.20 explains the working of SLM technique.

3.11.2 Tone Reservation (TR)

This method was introduced by J. Tellado and John M. Cioffi [61] for minimising the PAPR and further investigated by Brian S. Krongold and Douglas L. Jones [62]. This technique can be performed by reserving some sub carriers within the confined bandwidth for transmission to take place. There is no information in the reserved carriers and the tones reserved are assigned with an appropriate value.

In order to implement this scheme for PAPR reduction, generally the algorithm based on iterative clipping is taken up. There are some peak reduction tones (PRT's) derived by subdividing N subcarriers(tones). The tones are selected from among the signals having lower PAPR in time domain. The PRT positions are familiar to the transmitter as well as to the receiver. In FBMC/OQAM signals the peak power can be minimised to a great extent. Nevertheless, the same reduction technique does not have the same effect as in the OFDM systems. Due to the overlapped signals in FBMC /OQAM the Tone Reservation scheme has moderate effect on reducing the PAPR while it performed better in the case for the OFDM systems [17].

3.11.3 Tone Injection (TI)

In the Tone Injection technique, there is injection of a tone having decorous phase and frequency in the symbol, which in turn leads to add in one of the constellation points with those originally present. The injected tones forming the basis of new constellation points are used for the generation of low PAPR FBMC Symbols. Basically, it was intended to stretch the size of the constellation in a discipline that mapping on every point in original constellation is exhibited in the extended version of the constellation [52]. The extra carriers injected correspond to the extra degrees of freedom which help in the exploitation of minimization of PAPR.The signals are operated in time domain reducing the PAPR.TI is distortion free scheme with no loss in data rate but requires higher power.

3.11.4 Active Constellation Extension (ACE)

This scheme is connatural to the last-mentioned scheme for Tone Injection. Following the process to bring about ACE into practice [63], in the data block there is extension of the some of the outer signal constellation points to the exterior of original constellation in such a way that the PAPR is lowered for the block of data. The technique demands increased power during the transmission to take place.

3.11.5 Partial Transmit Sequence (PTS) for FBMC/OQAM:

Another PAPR reduction technique, PTS belongs to the category of probabilistic approach. It involves partitioning of the input sequence into V disjoint sub blocks. Let the input signal to the PTS block be S, given by

$$S_m^v = [S_1^v, S_2^v, \dots \dots .. S_M^v]^T \tag{3.32}$$

The scrambling is applied to each data block of the symbols and the one with least PAPR is transmitted in order to cause reduction in probability of high PAPR [1]. All the partitioned sub block values are multiplied to corresponding complex phase factors (b^v) such that,

$$b^v = e^{j\emptyset v} \text{ where v=1, 2……V.} \tag{3.33}$$

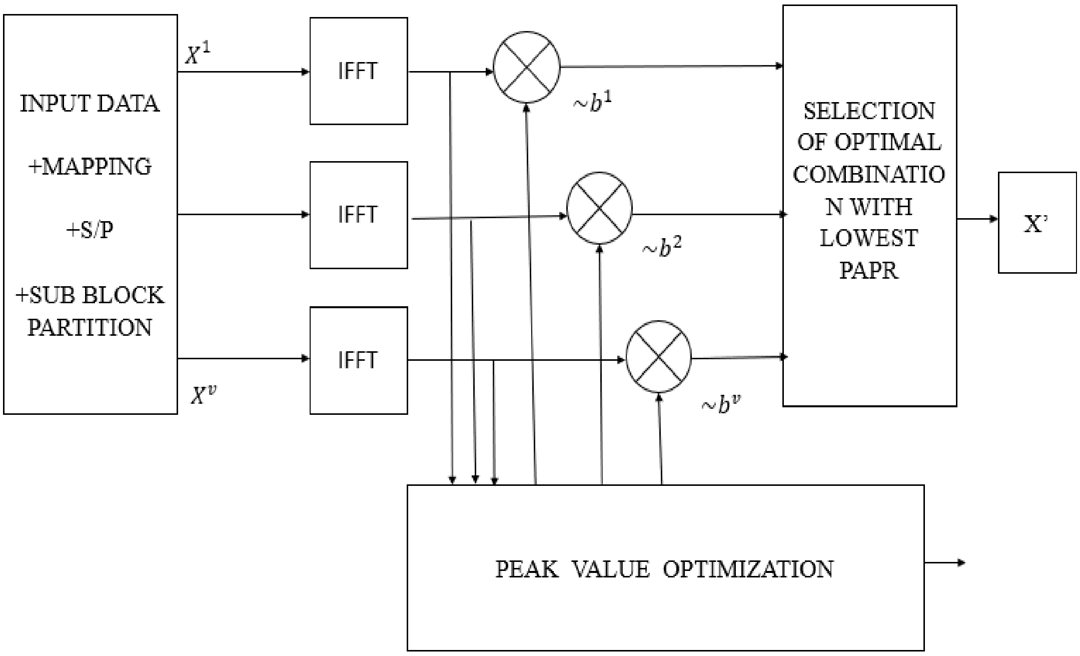

Figure 3.21. Block Diagram of Partial Transmit Sequence

The block diagram for the implementation given in Figure 3.21 explained the process for PTS. The elements of vector are usually selected from binary phase factor, the set {-1,1}. The signal in time domain after combining is given by

$$S_m(t) = \sum_{v=1}^{V} b^v \; S_m^v(t) \tag{3.34}$$

here, $\{S_m^v(t)\}$ represents the partial transmit signal. Now, the phase vector is chosen such that it yields minimum PAPR,

$$[\tilde{b}^1, \dots, \tilde{b}^V] = arg\; min_{[b^1, \dots b^V]}\; max_{0 \le t \le T} | \sum_{v=1}^{V} b^v \, S_m^v(t)|^2 \tag{3.35}$$

The vector with lowest PAPR value can be expressed as

$$\tilde{S}_m(t) = \sum_{v=1}^{V} \tilde{b}^v \; S_m(t) \tag{3.36}$$

Since the rotational phase is applied to independent transmit signals to reduce PAPR in PTS, the overlapping between the successive symbols in the structure of FBMC/OQAM subverts the optimum functioning of these multicarrier systems. The results simulated will be presented in next sections. A comparison for various PAPR reduction schemes is exhibited in Table 3.2

Table 3.2. Comparison table for PAPR Reduction Methods

Techniques	Distortion	Power increase	Data Rate Loss
Clipping and Filtering	Yes	No	No
Partial Transmit Sequence	No	No	Yes
Selected Mapping	No	No	Yes
Tone Reservation	No	Yes	Yes
Tone Injection	No	Yes	No
ACE	No	Yes	No
Companding	No	Yes	No

After the implementation of the conventional schemes for minimization, it was observed that some loop holes can be corrected by proposal for the hybrid technique. Higher computational complexity was attained as a consequence for the application of Partial Transmit Sequence, it involves the thorough investigation for optimal phase factors. By combining the two techniques in such a way that the "best of both worlds" i.e. the advantageous properties offered by each of them are combined to form a new-fangled scheme, so as to enhance the PAPR reduction capacity for the system. Both the schemes referred to as SLM and PTS offer distortion free transmission and there is no loss of power, their hybrid seems to be a well-chosen alternative for PAPR reduction in FBMC /OQAM systems.

Table 3.3 lists the parameters for simulations carried out on FBMC-OQAM systems which help in evaluating the execution of union scheme suggested for PAPR minimization.

Table 3.3 Simulation Parameters

Simulation Parameters	Specifications
Number of FBMC Symbols	128000
Number of subcarriers	64
Number of sub-blocks	4
Phase rotation factors	$b^{(v)} \in$ {+1, -1, +i, -i}
Phase rotation Sequences	$P^{(u)} \in$ {+1, -1}
Modulation Scheme	OQAM

3.12 PROPOSED HYBRID TECHNIQUE

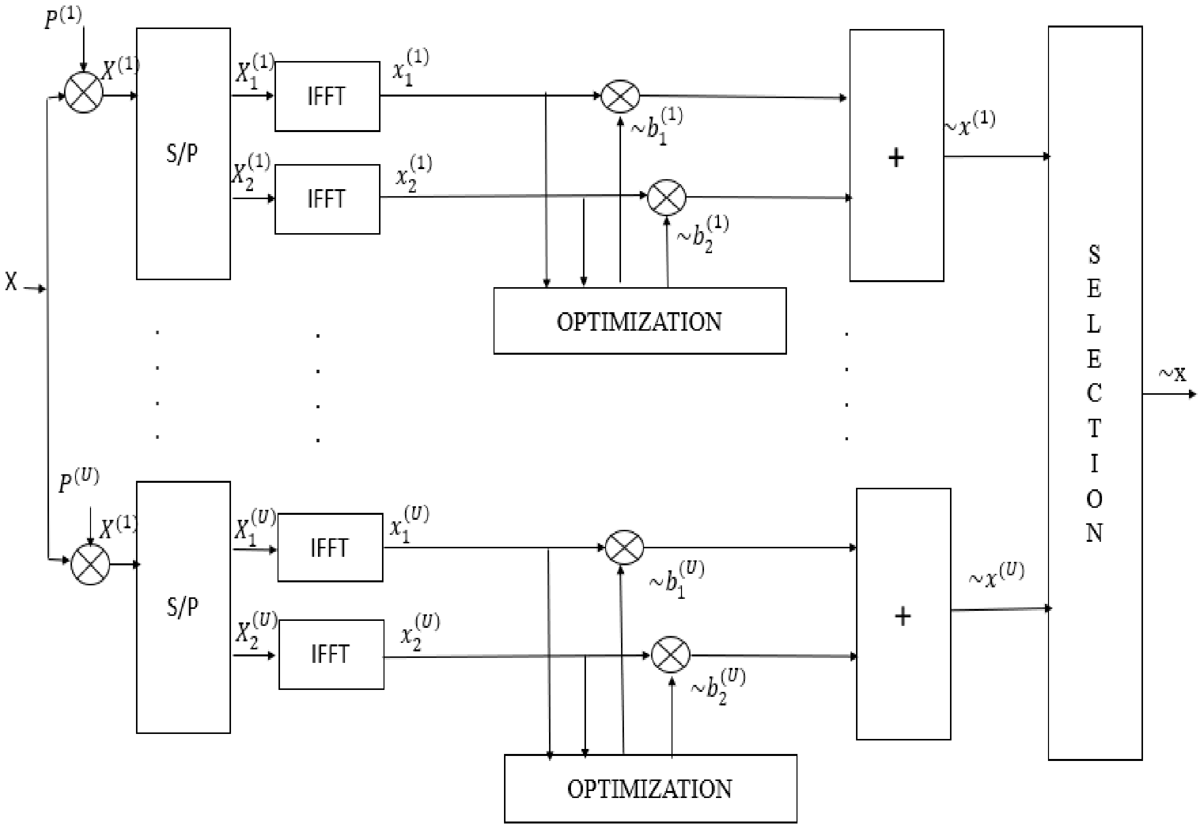

Figure 3.22 Block Diagram of Proposed Hybrid Scheme

The work proposed refers to a novel hybrid technique for PAPR reduction by combining SLM and PTS schemes. The benefits of both the schemes have been exploited in the Hybrid technique, relying on the belief that combining two techniques would enhance the performance overall. In both the schemes individually, there is no distortion, which holds true for the hybrid also. It does not cause increase in power. Hence, with same power the Hybrid PAPR Reduction technique can be applied. Firstly, the hybrid scheme formed by concatenating the SLM and PTS schemes is implemented. The original modulated symbol is phase rotated by applying it to a phase rotation matrix having Q phase rotation sequences, followed by the IFFT operation. The symbols after having the rotated phase are divided into W pairs of disarticulated sub blocks. Optimizing each of PTS blocks, the sub block values are calculated and the Optimization block with minimum PAPR is chosen by selecting the least PAPR valued signal in figure 3.22. The conventional SLM-PTS hybrid block diagram is shown.

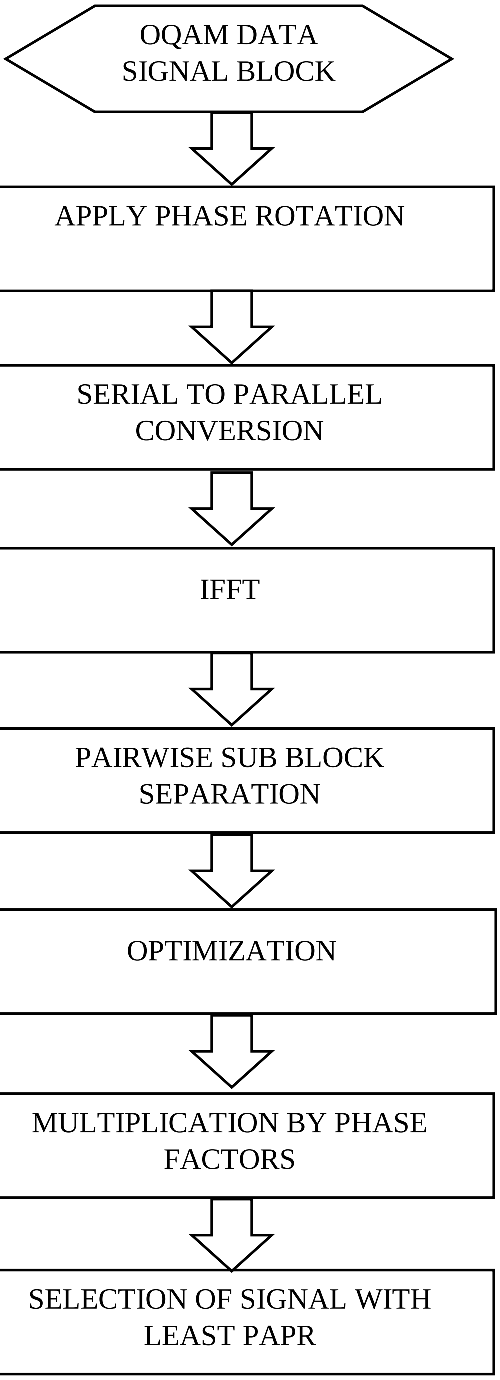

Figure 3.23. Procedure for Proposed Hybrid Scheme

The hybrid method is proposed by combining two conventional schemes for the reduction in peak power values in the FBMC systems. A step by step procedure for implementation of hybrid technique can be explained well by the Figure3.23. Both the techniques are merged in such away that profitable aspects for each of them are matched well and a significant reduction in PAPR is attained.

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

The simulated results are displayed for the proposed scheme. The FBMC symbols count used for transmission through Filter Bank Multicarrier Modulation is 128000 symbols. There are 64 subcarriers being utilized for carrying the data blocks. After the symbols subjected to the OQAM modulation process, the symbols are filtered via the PHYDYAS prototype filter. The filter with overlapping factor K=4 has been used. For carrying out of the Partial Transmit Sequence reduction scheme, the phase rotation sequences are +1 and -1. The phase rotation factors correspond to the values +1, -1, +i, -i, which provide rotation of phase in the sequences and then detection and evaluation of minimum PAPR values signal is determined. The impulse response for the PHYDYAS Filter are represented in figure 4.1.

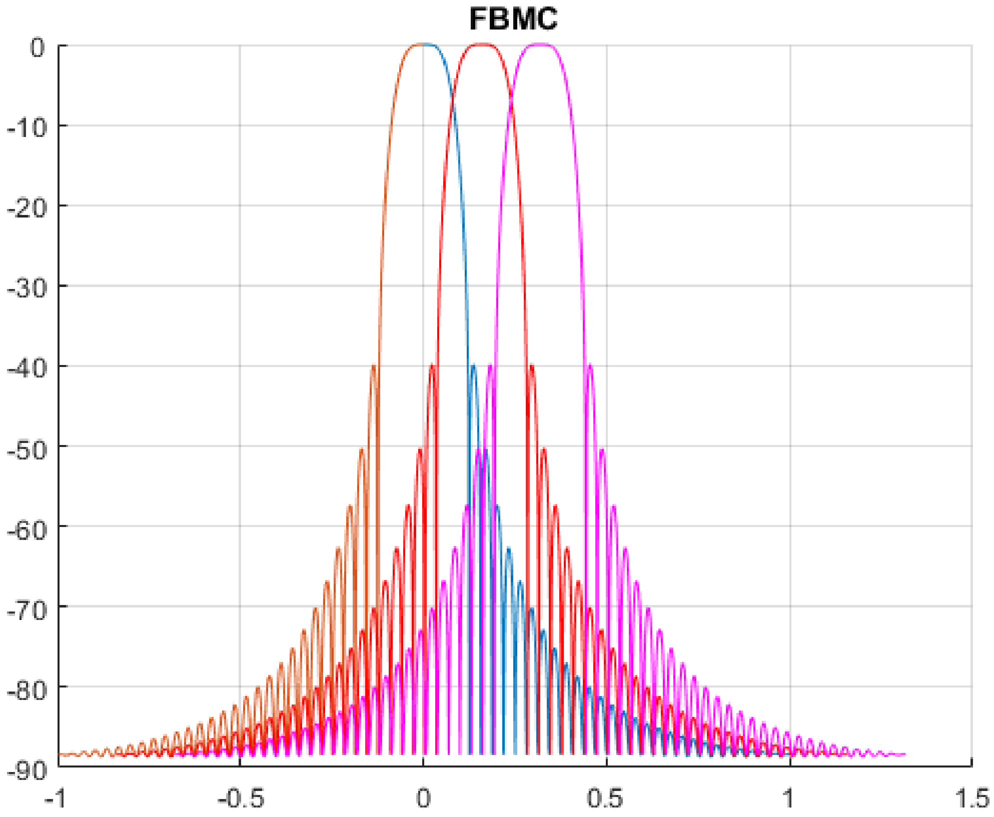

Figure 4.1 Frequency Response for PHYDYAS filter having 16 subcarriers for K=2,3,4

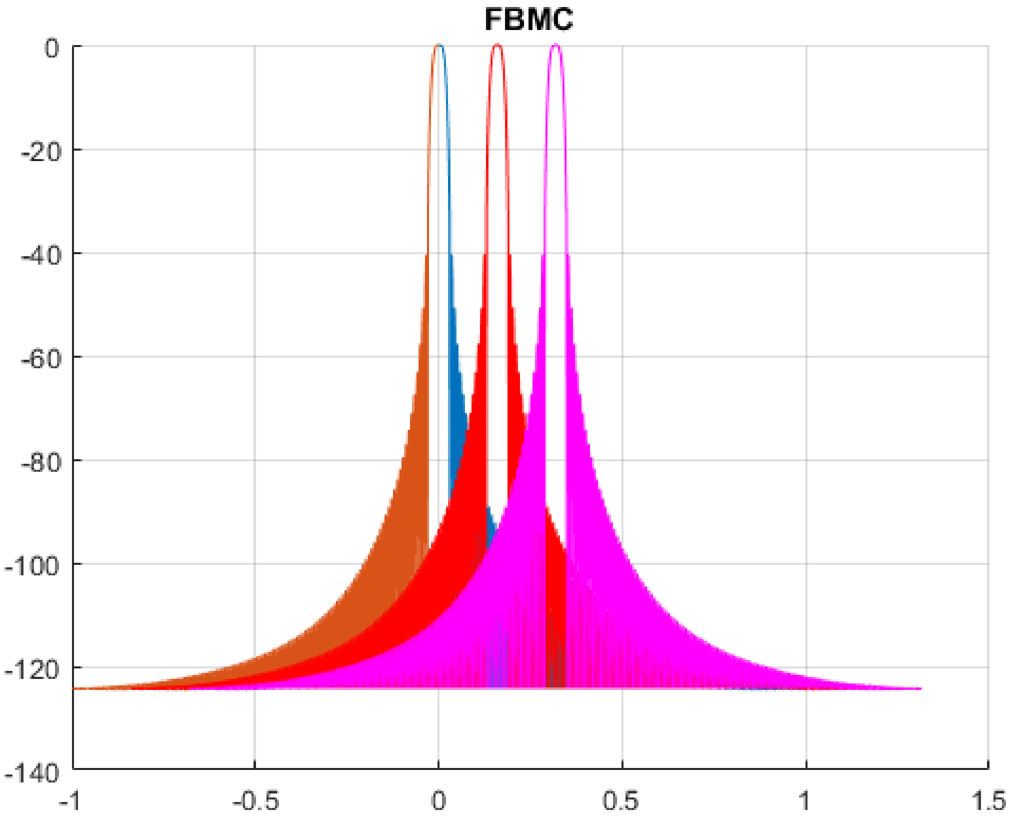

Figure 4.2 Frequency Response for PHYDYAS filter having 64 subcarriers for K=2,3,4

It exhibits the magnitude response for the different values of K, such that K=2,3,4. The response is also calculated by varying the number of subcarriers. Figure 4.1 shows the filter response for 16 subcarriers while figure 4.2 depicts the response with 64 subcarriers are considered.

4.2 BER VS SNR CURVES

BER is defined as the Bit Error Rate. It can be further elucidated as the counting for bits which are affected by the hinderances on their way during transmission and are full of error to the total bits which are processed i.e. transmitted or received. It is generally expressed as the negative power raised to 10. SNR refers to the Signal to Noise Ratio (SNR), given by the ratio of power of the transmitted signal to the noise power.

For a communication system, the performance of receiver can be determined through the BER versus SNR curve. Undoubtedly, the BER curve proves to be one of the finest criteria for assessment of the receiver operationality.

The bit error rate is calculated by transmitting a random signal which is modulated using OQAM technique with FBMC system. The performance was measured in presence of Additive White Gaussian Noise (AWGN) channel, which is more realistic representation of wireless communication channel. The plot for BER versus SNR for CP-OFDM and FBMC are depicted in the figure 4.3.

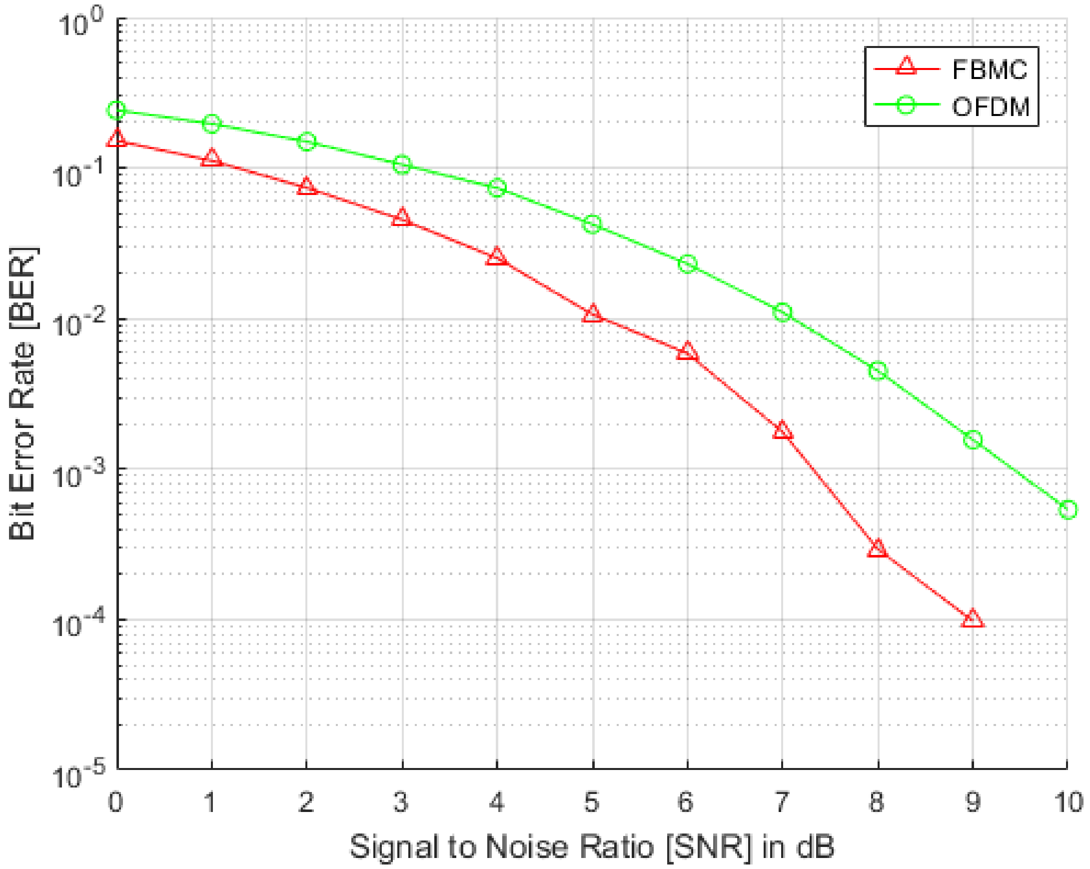

Figure 4.3 BER versus SNR for CP-OFDM & FBMC (for iterations=10)

It is worth noting that the BER versus SNR curve depicted in the figure 4.3 depicts the values for 10 iterations. The bit error rate performance of OQAM-FBMC system was far better than the superannuated CP-OFDM. The investigation for the calculation of Bit Error rates has also been done by varying the iterations count.

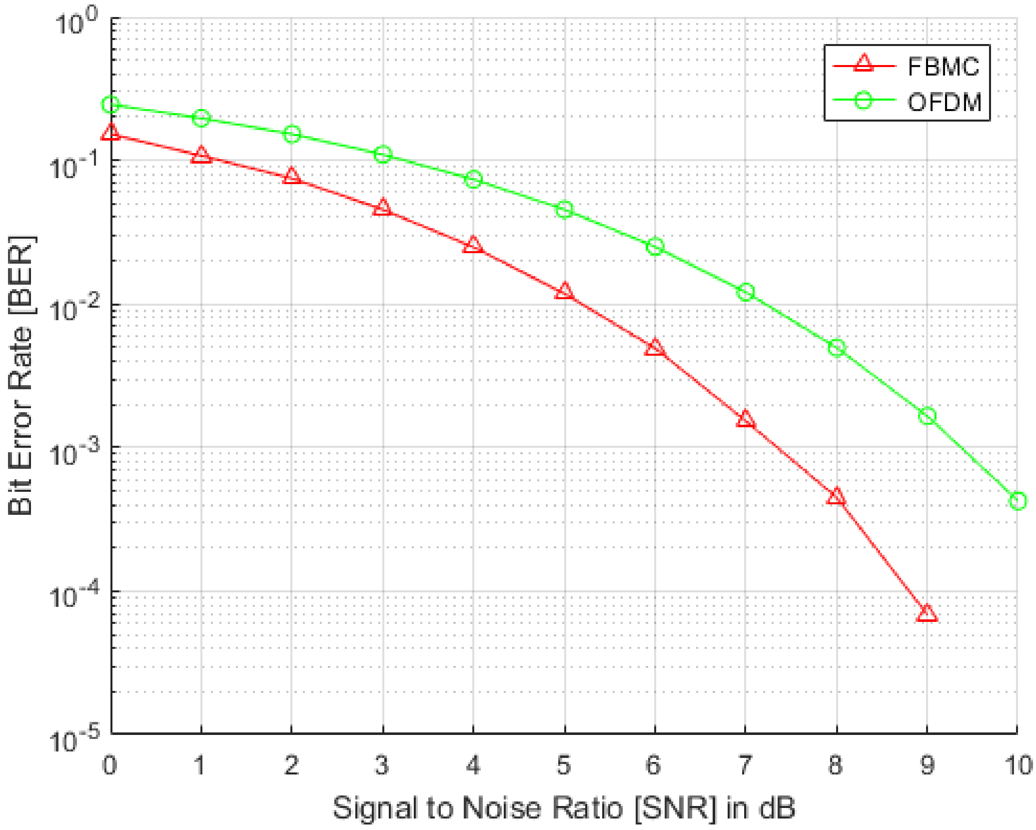

Figure 4.4 BER Vs SNR for CP-OFDM & FBMC (for iterations=100)

Figure 4.4 depicts the curves constituting the BER values over AWGN channel for the FBMC and for the OFDM. The above resultant curves are obtained for number of iterations equal to 100.

Also, increasing the number of iterations for both the technologies have caused an amelioration in the values, as depicted in the curves obtained. The FBMC /OQAM systems achieved better error rates as compared to that for the predominant OFDM systems.

4.3 PAPR CURVES

This section corresponds to the Peak to average Power ratio performance reduction obtained through the reduction techniques. The threshold value, is compared for a fixed probability of 10^{-3}.The CCDF value at 10^{-3} specifies the PAPR values exceeding threshold value in 1/1000 of samples.

The verification of simulation results and analysis of selected mapping, partial transmit sequence and their hybrid scheme are performed. The performance metrics of PAPR reduction of proposed hybrid scheme versus conventional SLM and PTS are investigated. The PHYDYAS filter is used with the overlapping factor equal to 4. To ensure that PAPR reduction to be executed successfully, the complementary cumulative distribution function (CCDF) has been utilized. It is observed that the hybrid scheme proposed has reduced the peak powers of the signal, thereby causing reduction in PAPR values.

The “original” named curve represents the PAPR value for the FBMC signal without any reduction application. The curve “Normal SLM” depicts the result after implementation of Selected Mapping reduction. The proposed method is intended to attain the overall more reduced PAPR values, since by combining the two schemes the meritorious qualities for each of them can be highlighted.

4.3.1 SELECTED MAPPING

Figure 4.5 depicts the performance of Selected Mapping technique applied to FBMC-OQAM systems. It is observed that application of SLM has reduced the PAPR values as compared to the original FBMC signal.

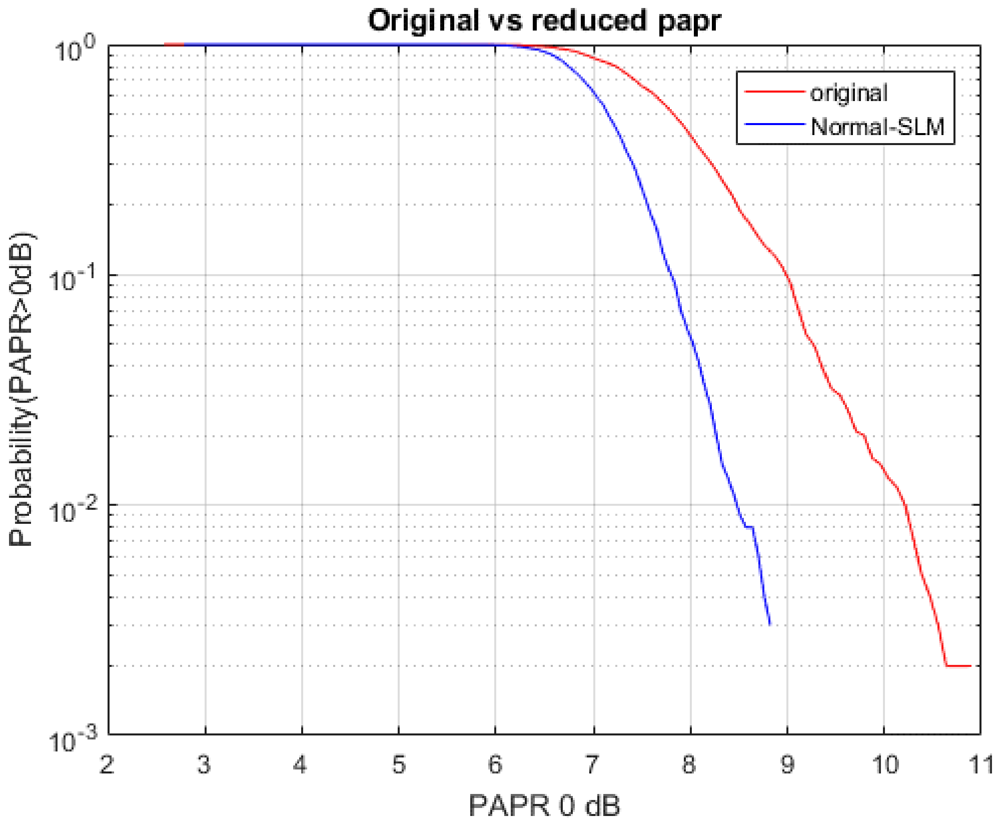

Figure 4.5 PAPR REDUCTION in FBMC using SLM

From the above Figure 4.5, it is observed that there is approximately 3dB improvement in PAPR values, by application of SLM technique. The PAPR reduction performance of FBMC can be measured by applying partial transmit sequence to the signal, which proves to cause minimization in the PAPR values, as shown in figure 4.6.

4.3.2 PARTIAL TRANSMIT SEQUENCE

The exploration of PTS scheme for minimizing PAPR is a probabilistic technique which ensures the mitigation of peak signals by finding the PAPR reduced signal optimally when the scrambling is applied to the input blocks with the help of phase vectors. The effects for multiple combination for phase factors are considered.

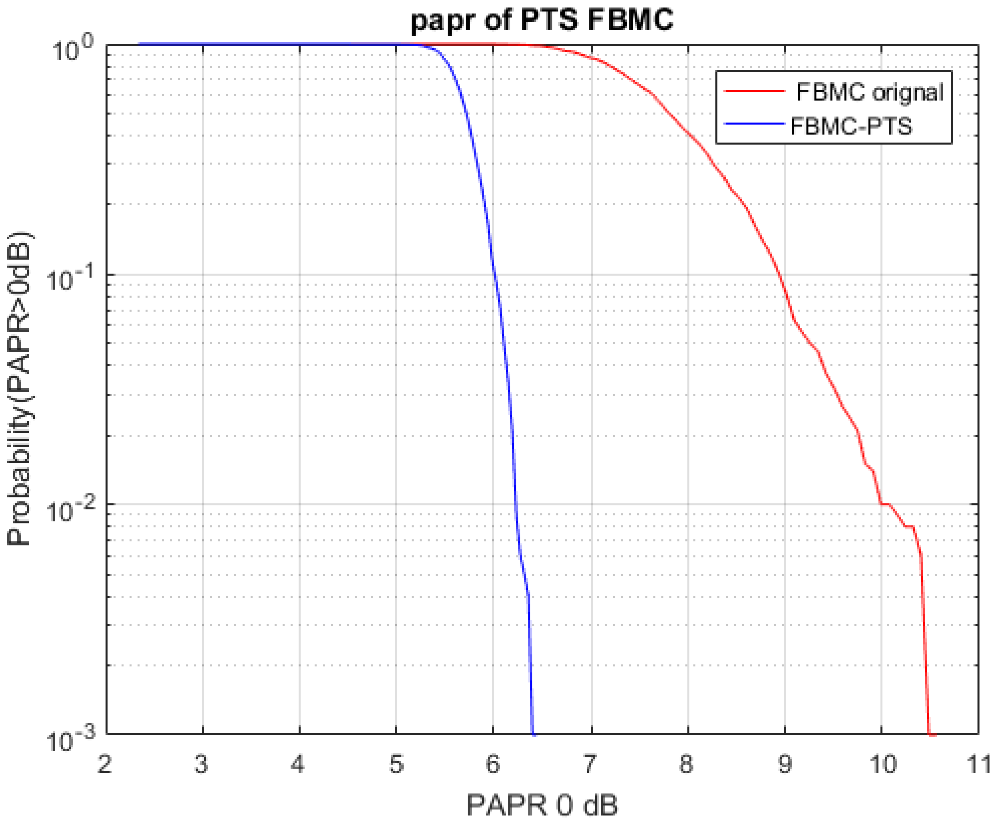

Figure 4.6 PAPR REDUCTION in FBMC using PTS

By employing the PTS method, it is observed that the reduction in PAPR values reaches to 6.5dB from the original signal value approximating to 11dB.It is worth noting that the reduction in PAPR attained by employing the partial transmit sequence method is manifold, which involves the splitting of transmitted block initially and then further processing to take place. The comparison for reducing the PAPR is evidently huge, as depicted in the Figure 4.6 if compared to application of conventional SLM.

4.3.3 PROPOSED HYBRID

The performance metrics of proposed hybrid technique are compared and analysed for the reduction in PAPR. As there is diminution in PAPR values, when they are subjected to schemes developed previously to avoid the high peak power problems relating to multicarrier systems. The effectuation of traditional schemes was examined to be fair enough but, in this work, it is proposed to combine the traditional methods to obtain improved results.

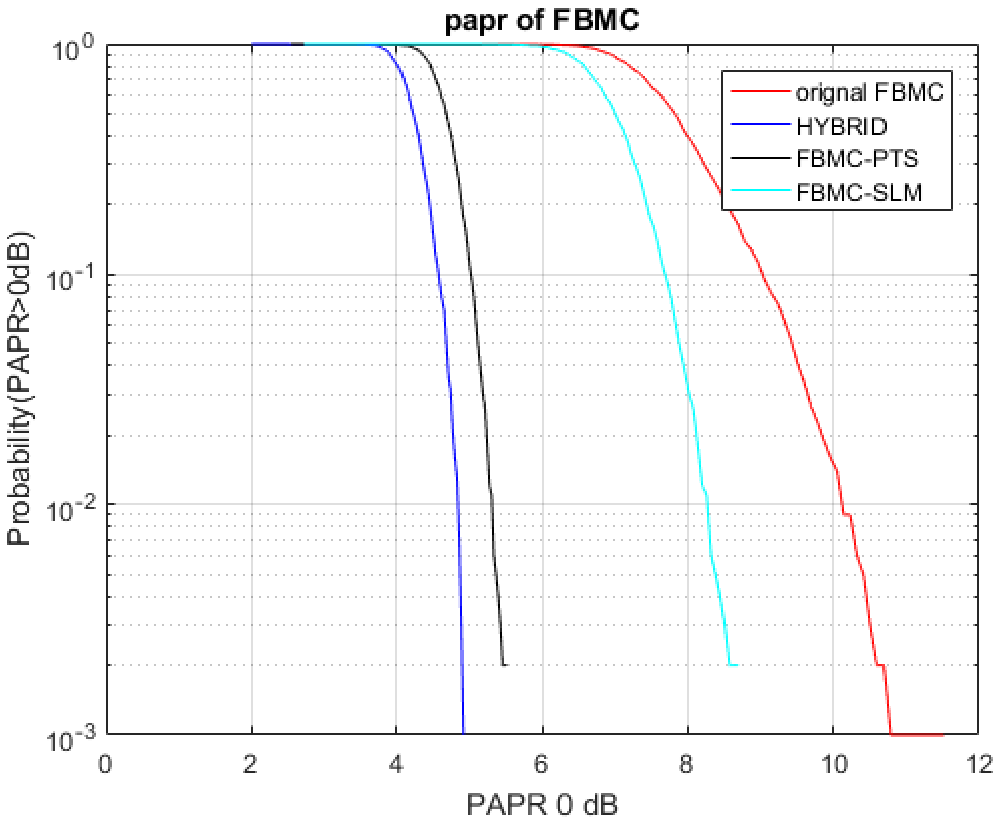

Figure 4.7 PAPR REDUCTION in FBMC using Hybrid SLM- PTS

Figure 4.7 depicts the curves relating to the hybrid scheme as well as the other two conventional reduction schemes for PAPR. From the figure 4.7, it is clear that the proposed scheme outperforms the conventional ones.

After implementing the reduction techniques for FBMC/OQAM systems for minimizing the PAPR, maximum PAPR reduction achieved is 5dB approximately due to the hybrid scheme proposed for reduction in PAPR. This shows that the proposed hybrid performs better than the existing reduction techniques.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The mobile communication has taken a new turn in its journey to provide better connectivity services, higher throughputs and data rate services to the ever-increasing users. From the simple landline calling facility to the present live streaming of videos, real time video calling, the wireless communication systems have come a long way. The technology growth has been tremendous. There are many candidate schemes capable for implementing the 5G network systems. A new scheme, referring to as OQAM-FBMC has emerged out to be probative waveform for the fifth generation. The shortcomings in CP-OFDM are expected to be met so that a spectrally efficient communication system having lower out of band radiations is unveiled. Firstly, the FBMC system is explored. The banks of filters are designed based on the Nyquist Criteria implied to both time and frequency domains, ensuring the perfect reconstruction of filters. The inherent feature for all MCM systems is the problem of higher peak to average values for power, which has also affected the FBMC systems as well. Various techniques for reduction of PAPR have been studied and implemented so far. In this work, scrambling techniques such as SLM and PTS are united. The proposed combination when subjected to the OQAM data signal block, its PAP ratio performance is convalesced. A significant reduction in the values is obtained. The combined scheme performance was at par with the reduction through the schemes individually implemented on the (OQAM)-FBMC systems. The results have been simulated and then investigated using the curves for CCDF plots. As it is evident from the simulations that the hybrid proposed combines the benefits of both of them by applying the phase rotation and selecting the mini mum value for signals with least PAPR.

The effectivity of Receiver can be estimated by the BER versus SNR curve. The signal undergoes transmission over AWGN channel for the FBMC system. The transmitter and receiver sections for the basic model are also tested by the design for receiver. The applied scheme intends to reduce the PAPR values but at the cost of increased computational complexity for the system implementation.

5.2 SCOPE OF FUTURE WORKS

1. There is a demand to study the issue for complexity of the polyphase structured systems, so that the systems become more proficient computationally.
2. Identification of the fundamental criterion for the designing of time frequency-based prototype filters. The criterion involves the pulse shaping which is well localised in time and frequency, allowing complex orthogonality and maximum spectral efficiency.
3. The exploration for various reduction techniques proposed for CP-OFDM systems to be applied to the FBMC based MCM, it is observed that some of them can not be applied directly to the OQAM based systems as proposed for the OFDM systems.

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