A Unifying Network of Filter Bank Multicarrier Modulation for 5G Technologies

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***Abstract*— Filter bank multicarrier is a modulation technique origin from orthogonal frequency division modulation which implements filters in multicarrier modulation system. In this paper, we address the shortcomings of OFDM and show that filter bank multicarrier (FBMC) technique could be a more effective Solution for 5G applications. Filter bank multicarrier modulation has so many advantages over OFDM and is considered to be a more competitive waveform in the future generation (5G) cellular communication systems. Here we are dealing with both perfect reconstruction FBMC (PR-FBMC) and imperfect reconstruction FBMC (iPR-FBMC). Overall, we provide a new framework, discussion and performance evaluation of FBMC and compare it to OFDM based schemes. Using MATLAB, OFDM system and FBMC has been tested with different digital modulation schemes including and compare its system parameters. FBMC system has better usage of available channel capacity and is able to offer high data rate and spectral efficiency. Simulation shows that this technology is developed to high performance parameters compared to other schemes. This paper explains the limitations of OFDM and provides an overview of implementing prototype filters with FBMC system.**

Keywords*— CP, FBMC, FFT, ICI, OFDM, IFFT, ISI, MCM, MIMO.

I. INTRODUCTION

As of today OFDM has been the dominant technology for broadband multicarrier modulation. OFDM is very attractive modulation as well as multiplexing technique that is used in optical wireless communication system. Several advantages of OFDM are good spectrum utilization and channel robustness. However certain applications such as cognitive radio and uplink communication OFDM may be undesirable due to some of its disadvantages. OFDM has drawbacks like unable to maintain orthogonality due to ISI among consecutive multicarrier symbols. The existing technique in OFDM to counter this issue is to introduce a cyclic prefix (CP).This introduces time overhead in the communication, resulting into a loss of spectral efficiency and low data rate in AWGN channel. The CSI corresponding to each training blocks are first estimated and then tracked and removed with the help of demodulated data. This technique is called Decision Directed Channel Estimation (DDCE) [1].

OFDM is more sensitive to time and frequency synchronization. The synchronization problem includes carrier frequency offset (CFO) and symbol time offset (STO). This is mainly due to the mismatch between the local oscillator at the transmitter and receiver. In STO, offset is affected in the frequency domain. This synchronization error destroys the orthogonality among the sub carriers which causes inter symbol interference and intercarrier interference (ICI) [2].

The technique used by FBMC to overcome these problems is to keep the symbol duration unchanged, thereby avoiding the time overhead issues. This is done by implementing filter bank with IFFT/FFT operation. The basic FBMC communication system has well designed prototype filter, the spectrum of each subcarrier can be reduced. This property makes FBMC an ideal choice for many applications such as cognitive radio and uplink networks. The polyphase structures are proposed for the implementation of FBMC system. Prototype filter design is based on nyquist theory. One of the straight forward methods is consider frequency confidents and apply symmetry conditions in nyquist filters. This technique uses pilot added and blind synchronization methods to differentiate carrier frequency of the incoming signal and oscillation signal used to demodulate it [3].

The basic principles of FBMC include filtered multitoned (FMT) and staggered multitoned (SMT) [4].However, SMT introduced interference among the subcarriers. So the proposed FBMC scheme which reduced ICI and exhibits high spectral efficiency than OFDM.In Multiple Input Multiple Output system (MIMO), multiple antennas are used in both transmitter and receiver which allows simultaneous transmission and reception. Conventional Single Input Single Output (SISO), antenna is limited in meeting the rising demands of future applications.Now a day's communication requires high transmission rate and quality of services (QOS). MIMO OFDM is one of promising technology for high data rate services. The main of this paper is to avoid interference by adopting interference cancellation(IC). Particularly successive IC (SIC) method is in terms of high BER performance and thus yielding to the overall system robustness. This SIC implementation for both single antenna and multiple antenna systems requires advanced DSP unit at receiver end. Simulation results shows that performance complexity tradeoff (PCT) levels are tested for different antenna configurations and it was seen that MIMO OFDM has the appropriate PCT level.

The major challenges faced by wireless communication are availability of bandwidth and transmission power. Also it suffers from fading and interference. All these requirements can be achieved by introducing channel impairments are mitigated by using equalization methods. BER performance of system has been tested for different techniques such as zero forcing (ZF), Minimum Mean Square Error (MMSE) and Maximum Likelihood (ML). Equalization methods are used to compare ISI created by multipath channels [5-6].

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The 5G cellular mobile devices are quick enough to communicate with each other than 4g and LTE systems. The main of 5G is to improve communication speed, at low cost, low latency and better implementation than the previous generation. This can have achieved by adopting FBMC system. In order to increase the spectral efficiency even more and to improve BER performance, this paper introduces filter bank multicarrier technology. The theoretical expression of the PSD called FFT-FBMC system which reduces interference in the adjacent sub bands of about 15.8dB [7]. Simulation PSD curves shows that FFT-FBMC spectrum is much confined than conventional FBMC system. The added filter enhances the spectral efficiency. Additionally, FBMC also reduces the spectrum consumed by each guard band. Here equalizer at the receiver end equalizes the data symbols and then it is converted into bits. This paper proposed conventional ZF and MMSE equalizers and compared the Signal to Error Ratio(SER).it was noted that ZF and Minimum Mean Square Error (MMSE) FBMC has low computational time compared to OFDM system [8].

Filter Bank Multicarrier, FBMC is a form of multi-carrier modulation that origins within OFDM. It aims to overcome some of the disadvantages of OFDM. FBMC has a much better usage of the available channel capacity and is able to offer higher data rates and higher level of spectrum efficiency. FBMC system offers high spectral efficiency, data rate and BER performance. The design of wide bandwidth and high dynamic range systems with FBMC provides significant RF development challenges.FBMC is a multicarrier modulation (MCM) technique in which a prototype filter is used to achieve certain goals such as minimizing ISI, ICI and increasing the spectral efficiency. More importantly, prototype filter is introduced with anew goal of improving performance parameters such as data rate, throughput and BER performance. FBMC is definitely a promising technique for use in upcoming 5G systems [9].

This paper addresses the shortcomings of OFDM and shows that FBMC could be a more effective solution. In existing FBMC, prototype filter is designed to meet perfect reconstruction (PR) condition to maintain sub band orthogonality. Differ from OFDM, FBMC including synthesis filter bank and analysis filter bank, so that we can separate the sub bands almost perfectly in the frequency domain. Due to this property FBMC is more robust to CFO than OFDM scheme. Cyclic prefix is not used in FBMC, which leads to high spectral efficiency for long data packets. In this paper we analyses a performance comparison between OFDM method and FBMC. The OFDM symbol has a high peak to average power ratio (PAPR). This high PAPR causes non linearity effects on the transmitted OFDM symbols, spectrum spreading, intermodulation, changing signal constellation and interference to symbols. It is more sensitive to carrier frequency offset and interferences. Meanwhile FBMC technique offers low PAPR and better performance parameters compared to other schemes. Filter bank multicarrier techniques are resilience to multipath fading, enable flexible spectrum allocation and can approach the theoretical capacity limits in communications. To satisfy the upcoming needs, multiple input multiple output (MIMO) technologies are introduced with FBMC system. Deploying multiple antennas at both ends has high link reliability and the throughput with respect to single-antenna configurations. MIMO-FBMC have high data rate, low latency, high spectral efficiency and support a huge no of devices.

II. SYSTEM MODEL

A. *Existing Perfect Reconstruction Method*

The perfect reconstruction method (OFDM) is a transmission technique where a single set of data is transmitted over a number of sub-carrier. OFDM takes the advantage like resilience to interference, resilience to narrow band fading and multipath effect. The main idea of OFDM is to split the total available bandwidth into a number of subcarriers which reduces the inter-symbol-interference, power consumption and increases the capacity and efficiency of the system. High Peak- Average-Power-Ratio (PAPR) is one of the disadvantages of OFDM which reduces the efficiency of system. In this paper, we have proposed prototype filter which eliminate PAPR effect in OFDM signals.

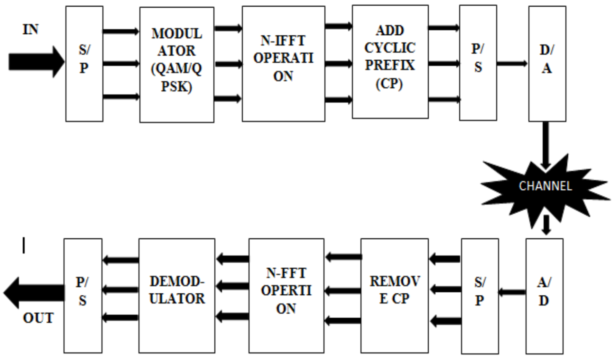

Fig 1. OFDM Architecture

The OFDM architecture is implemented by combining the different block as shown in Fig 1.The function of random generator is used to generate a random uniform data in the range of (0, M-1), where is the Mary number. The Mary can be either a scalar or a vector. If it is defined as a scalar, then all output random variables are independent and identically distributed. Now the data is serial which is given to a serial to parallel converter.

A serial to parallel converter formatted data into word size required for transmission and shifted it into parallel format. Once the symbol has been allocated to each of the subcarriers then they are phased mapped accordance with modulating technique. Different modulation scheme can be adopted based on channel condition, data rate, robustness, throughput and channel bandwidth (i.e., QPSK, QAM). Modulation to OFDM sub channels can be made adaptive after getting information and estimation of channel at transmitter.

The Orthogonality of subcarrier is maintained and the frequency domain signals are converted into a time domain by using IFFT Mapping. If the length of the guard interval is longer than the duration of the channel impulse response, ISI can be eliminated. However, the insertion of the guard interval reduces the transmission efficiency. Therefore, the guard interval must be chosen as sufficiently small. The most commonly used guard interval is known as Cyclic Prefix (CP).Now the modulated OFDM data is converted into analog by using digital to analog converter (DAC). The transmitted OFDM signals are transmitted through wireless channels. OFDM technique transmits the data over a large number of

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carriers at different frequencies. This spacing provides the orthogonality which avoids the receivers to see wrong frequencies.

In comparison with other multi-carrier techniques, like CDMA, OFDM prevents the Inter Symbol Interference (ISI) by adding a cyclic prefix. The key features of OFDM are the IFFT/FFT pair. These mathematical tools are used to transform several signals on different carriers from the frequency domain to the time domain in the IFFT and from the time domain to the frequency domain in the FFT.The receiver part perform the down conversion of the signal and convert the signal into digital domain by using ADC. The synchronization is also needed during reception. The OFDM symbol is demodulated by using a FFT.

B. FBMC Architecture

We can overcome most of the shortcomings in the OFDM by using FBMC technique. In FBMC, we utilize filter banks at both transmitter and receiver end are observed to be well placed, hence the ISI in OFDM can be eliminated. On the other hand, it helps us to eliminate the effects of cyclic prefix. Let us now observe the structural characteristics.

On the transmitter side we use an array of N filters in filter bands hence we can process N signals at a given time. The transmitter section uses analysis filter and receiver section uses synthesis filter bank. Similar to OFDM the input goes through S/P and then passed through the analysis filter bank. Then the signal again is converted and the output observed is in absolute serial form.

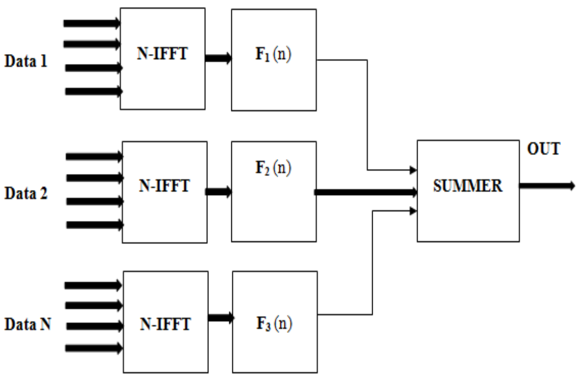

Fig 2. FBMC Transmitter

Fig 2. and Fig 3. show the transmitter and receiver design for FBMC respectively. The transmitter structure of FBMC includes filters rather than CP-OFDM.The Binary data is passed through transmitter where an N point IFFT is performed. Before transmitting the signal, it is passed through a filter to avoid interferences. On the receiver side, a band pass filter filters the incoming signal then it is passed through N point FFT operation is performed. The equalizer used at receiver equalizes the data symbols.

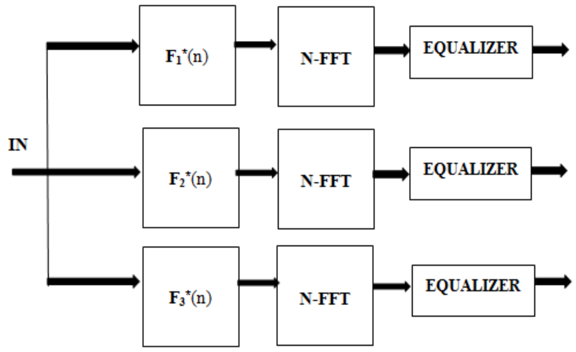

Fig 3. FBMC Receiver

C. Prototype Filter Design

Digital prototypes filter design is based on the Nyquist theory. Design criteria states that the impulse response of the transmission filter must cross the zero axis at all the integer multiples of the symbol period. The condition translates in the frequency domain by applying the symmetry condition about the cut-off frequency, which is half the symbol rate. Later, a straightforward method to design a prototype filter is to consider the frequency coefficients (F) and impose the symmetry condition. In transmission systems, the Nyquist filter is generally split into two parts, a half filter in the transmitter and a half filter in the receiver. Then, the symmetry condition is satisfied by the frequency coefficients [14]. The frequency coefficients of the half side filter obtained for K=2, 3 and 4 are given in Table I

Table I: Frequency prototype filter coefficients

k	F0	F1	F2	F3
2	1	0.707	0	0
3	1	0.914	0.412	0
4	1	0.971	0.707	0.235

The frequency response is obtained from the frequency coefficients through the interpolation formula for sampled signals are given below:

$$H(f) = \sum_{k=-(k-1)}^{k-1} Hk \left\{ \sin\left(\pi\left(f-\frac{k}{Mk}\right)MK\right) \middle| MK\sin\left(\pi\left(f-\frac{k}{Mk}\right)\right) \right\} \quad (1)$$

The impulse response h (t) of the digital filter is given by the inverse Fourier transform of the frequency response, which is given by:

$$h(t) = 1 + 2\sum_{k=1}^{k-1} Hk\cos\left(2\pi\left(\frac{kt}{KT}\right)\right) \quad (2)$$

Prototype filter design criterions are:

- Each filter should have a flat pass band over the subcarrier in the sub band.

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- Each filter must have a sharp transition band in order to reduce the size of the guard bands.
- The stop band attenuation should be sufficient enough to avoid ISI between the stop and pass band

III. SIMULATION PARAMETERS

Filter bank multi-carrier technique has many advantages over other modulation technique and is considered to be perfect waveform in the future cellular communications. Simulation results show that unlike OFDM, whose system parameters are sufficiently high for 5G applications. Perfect synchronization is assumed in the simulation set up in order to prevent ISI and Inter Carrier Interference.

Then we select the cyclic prefix to be 10% of the transmitted OFDM symbol duration such that the maximum average path gain is less than this chosen cyclic prefix. More so, for simulation set up we ensure that each transmission always has a zero path delay which closely matches a perfect synchronization. Other simulation parameters used in the OFDM system simulation design are as shown in Table II.

Table II: Simulation Parameters of FBMC

Parameters	Values
Number of FFT points	1024
Number of Guard bands	212
Sub band spacing	10KHz
Number of symbols	100
Bits per subcarrier	4
Overlapping factor	4
Filter length	43
Filter coefficients	F1=0.791,F2=0.707, F3=0.235

IV. RESULTS AND DISCUSSION

In the paper, the simulated Bit Error Rate (BER), Peak to Average Power (PAPR) and Power Spectral Density will be compared to OFDM and FBMC.This work uses QAM as modulation method.

Fig 4. and Fig 5. Represents the spectrum of OFDM and FBMC which shows when carriers are modulated in OFDM, side lobes spread out on either side. However, FBMC with a filter bank system, the filters are used to remove the noise. Therefore, in FBMC we get much cleaner carrier results. Also FBMC Provide high spectral efficiency and data rate. FBMC is more spectrum efficient than OFDM system. The cyclic prefix required for OFDM is not needed in FBMC thereby freeing up more space for real data. Fig 6.shows the SNR VS BER curve of OFDM and FBMC.Overall, we provide a unifying frame work that offers a low BER, high spectral efficiency and more competitive waveform for 5G communication compared to OFDM.

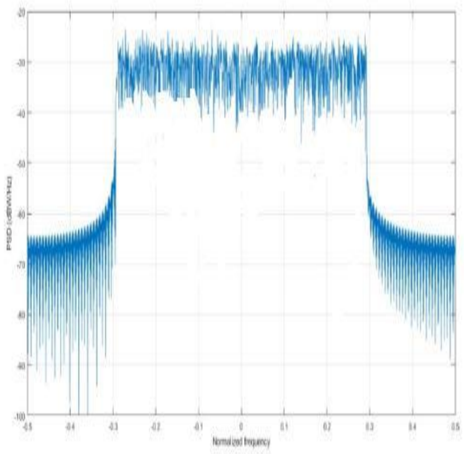

Fig 4. Spectrum of OFDM

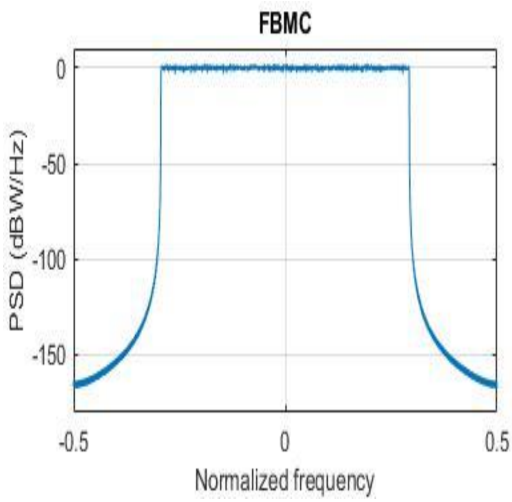

Fig 5. Spectrum of FBMC

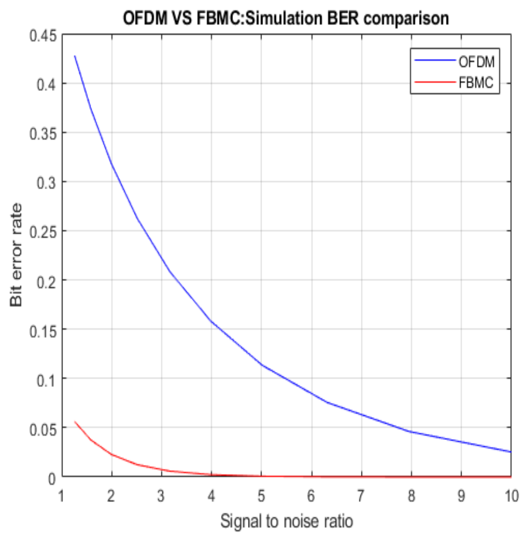

Fig 6. SNR VS BER Comparison

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In Fig 7.the prototype filters of OFDM and FBMC magnitude responses have been plotted against the normalized frequency is implemented. We judge the magnitude response of prototype filter for OFDM and FBMC with overlapping factor K=4.It indicates that the magnitude response of OFDM is constant throughout the frequency which means it is more affected by PAPR which reduces the efficiency of the system. Initially the response of FBMC is more than 30dB and it reduces with increase in frequency. Simulation results shows that in FBMC peak to average power ratio is reduced to 4.512. FBMC has better usage of the available channel capacity and is able to offer higher data rates within a given radio spectrum bandwidth. Parameter comparison of OFDM and FBMC are shown in Table III.

V. CONCLUSION

5G cellular communication system expected to have high data rate, low latency, and high spectral efficiency and support a huge no of devices. FBMC is capable of improving the system performance. As the number of transmit and receive antennas increase, enhances data rate and support large amount of data. In this paper we are analyzing the performance of FBMC and OFDM with QAM modulation. It is observed that QAM with FBMC has better BER performance compared to other modulation schemes. Hence, it can be concluded that FBMC can be a better choice for future generation cellular communication systems.Another area where there is a need for further study is application of FBMC systems to MIMO channels.

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