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Performance Evaluation of Multi-carrier Modulation Techniques for Next Generation Wireless Systems

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Abstract: Multicarrier modulation techniques are gaining attention to support high data transmission rate in next generation wireless communication systems. With increasing number of users and to support diversified services, more efficient and reliable modulation techniques are required. This work presents a comparative analysis of three multicarrier modulation techniques as OFDM, UFMC and FBMC on the basis of Peak To Average Power Ratio (PAPR) and Power Spectral Density (PSD). OFDM offers comparatively lower value of PAPR but suffers from the limitation of poor spectral efficiency. UFMC, on the other hand provides better spectral efficiency but at the cost of high PAPR. FBMC provides better spectral efficiency and rejection to inter-symbol interference as compared with OFDM but complexity is also increased. In this work, these modulation techniques have been analyzed for variation in FFT size and bits/sub carrier. QAM is used as basic modulation method for performance evaluation of three multicarrier modulation techniques.

Keywords: FFT, OFDM, FBMC, UFMC, PAPR, PSD.

I. INTRODUCTION

In this modern era of technology, Multicarrier modulation is a need of wireless communication [1]. For this purpose various multicarrier modulation techniques have been proposed so that increasing number of users and demand of higher data rates can be served [2][3]. Orthogonal Frequency division Multiplexing is one of the most widely used modulation technique. It is being used in Long Term Evaluation (LTE) and LTE advanced because of its simple and efficient modulation process and it can support high data transmission rate[3] but it requires highly synchronized system and cyclic prefix used in waveform generation making it less spectral efficient. Next generation wireless communication systems require such a modulation technique which can support high data transmission rate as well as high spectral efficiency.

For this purpose new modulation techniques have been proposed in literature. Among the techniques available, UFMC and FBMC seems to be attractive [4]. In FBMC each subcarrier is individually filtered, resulting in reduction of inter-carrier interference (ICI) [5]. However, filter length is much greater than OFDM systems making it unsuitable for short bursts data transmission. Universal Filtered Multi-Carrier (UFMC) is a novel multi-carrier modulation technique [6], having advantages of OFDM and FBMC. In OFDM, one filter is applied on the entire band whereas in FBMC, filters are applied on each subcarrier individually. In UFMC, filter is utilized on sub band blocks, i.e. groups of subcarriers. This allows reducing the filter length considerably as compared to FBMC. So, UFMC is less complex like OFDM and provides better sub carrier separation like FBMC [7]. All these techniques are suffering from drawback of high PAPR and PSD is also of a great concern.

The focus of this paper is to do a comparative analysis among three (UFMC, FBMC, OFDM) multicarrier modulation techniques in light of PAPR and PSD with same system parameters as FFT size, bits per sub carrier and modulation type.

The rest of the paper is organized as: section II provides conceptual introduction of three multicarrier modulation techniques. Section III presents simulation setup designed for comparison. Section IV presents effect of design parameters on different modulation methods. Section V concludes the work with final remarks.

II. MULTICARRIER MODULATION

The basic idea behind multicarrier modulation is to divide the transmitted bit stream into many sub streams and transmit on many sub channels. Typically the sub channels are orthogonal under ideal propagation conditions but the new modulation techniques like UFMC are non-orthogonal[8][9]. The data rate on each of the sub channels is much less than the total data rate, and the corresponding sub channel bandwidth is much less than the total system bandwidth. This ensures that the sub streams will not experience from significant ISI.Three multi carrier modulation schemes can be given as:

1) Orthogonal Frequency Division Multiplexing (OFDM): Fig. 1-1 shows the basic block diagram for an OFDM transmitter. The digital data is mapped to complex symbols such as QPSK, 16QAM, 64QAM or 256QAM etc. A serial to parallel converter turns the data stream into N streams, which correspond to the different carrier frequencies f_0, f_1, f_2, etc which are orthogonal to each other. Then the signal is converted from frequency into time domain by an Inverse Fast Fourier Transform (IFFT). To increase robustness against Inter-Symbol Interference (ISI) caused by multipath propagation the total symbol duration is further increased by adding a Cyclic Prefix (CP). A CP is a copy of the tail of a symbol placed at its beginning. In an OFDM system filtering is applied to entire band in single shot and that's why the system is less complex and easy to implement than other multi carrier modulation techniques. The only drawback of OFDM is CP insertion because it makes the system less spectral efficient as compare to other multicarrier modulation techniques like FBMC or UFMC etc.

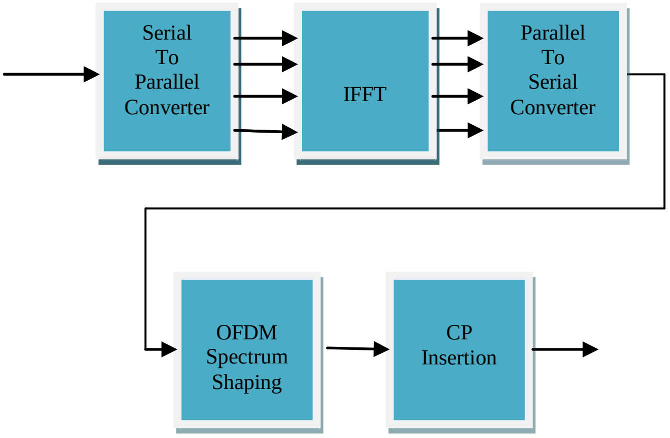

Fig. 1-1 OFDM Transmitter

2) *Filter-Bank Multi-Carrier (FBMC):* In FBMC system filtering is applied on per sub carrier basis which provides better sub carrier separation and there is not any need of cyclic prefix like OFDM and hence the system is having better spectral efficiency than that of OFDM. The basic block diagram of FBMC is given in Fig. 1-2.

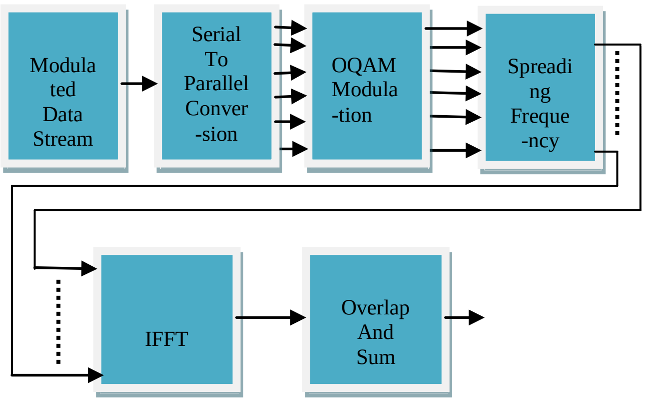

Fig. 1-2 FBMC Transmitter Stage

In FBMC system prototype filter is used with over sampling factor K this oversampling factor determines that how many symbols are overlapped to generate final symbol. Symbol with K=4 is showed in Fig. 1-3

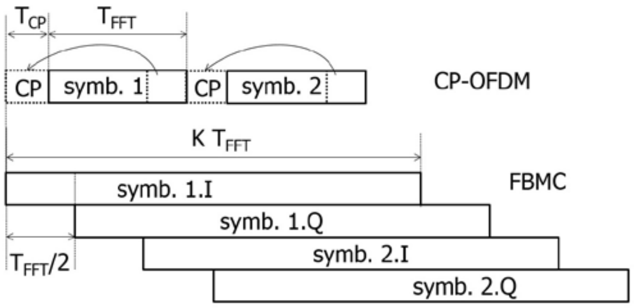

Fig. 1-3 OFDM (top) and FBMC (bottom) Frame

FBMC provides better sub carrier separation because it filters the signal on per sub carrier basis but larger FFT size and the filtering method used in signal generation makes the system much more complex than that of OFDM.

3) *Universal Filter Multi Carrier (UFMC):* UFMC is a way between the two discussed above as it applies filtering to subsets of the complete band instead of single subcarriers or the complete band. UFMC provides advantages of both OFDM and FBMC; it is having better sub carrier separation like FBMC and less complexity like OFDM systems. Basic block diagram of UFMC wave form generation is given in Fig. 1-4

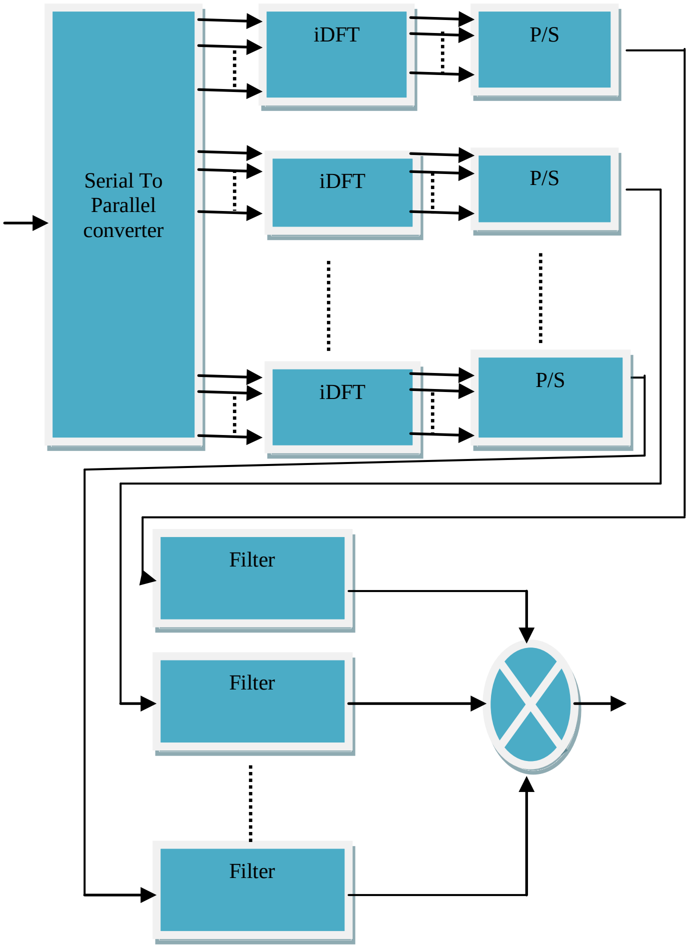

Fig. 1-4 UFMC Transmitter stage

The need of multiple carrier modulation is to serve large number of users and also to support higher data rates. All these purposed multiple modulation techniques are having various advantages and drawbacks. Performance of these multi carrier modulations can be evaluated on the basis of Power Spectral Density (PSD) and Peak To Average Power Ratio (PAPR) which can be defined as:

1) Peak To Average Power Ratio (PAPR): All multicarrier modulations techniques are suffering from drawback of higher Peak To Average Power Ratio [10]. Because in multicarrier modulation the input data stream is divided into multiple sub streams which are known as sub carriers. Then these sub-carriers are independently modulated at different carrier frequencies and can give a large PAPR when added up coherently for transmission purpose. If N signals are added with the same phase they produce a peak power that is N times the average power of the signal. So multicarrier signals have a very large PAPR, which is very sensitive to nonlinearity of the high power amplifier. PAPR in multi carrier modulation can be defined as:

$$\text{PAPR} = \left(\frac{max\{|d[n]|^2\}}{E\{|d[n]|^2\}}\right) \qquad \ldots\ldots\ldots\ldots(1)$$

where, $|d[n]|$ is the amplitude of d[n] and E denote the expectation of the signal.

Higher PAPR can cause saturation in power amplifiers, leading to inter modulation products among the subcarriers and disturbing out of band energy. Therefore, it is desirable to reduce the PAPR [11][12].

2) Power Spectral Density (PSD): The Power spectral density refers to the spectral energy distribution that would be found per unit time.

There are various design factors which can affect performance of UFMC [13][14], FBMC [15] and OFDM [16]. In this work, effect of FFT size, Bits per Sub carrier and Modulation Order on all these multicarrier modulation techniques have been observed.

III. SIMULATION SETUP

In this work, three multicarrier modulation techniques UFMC, FBMC and OFDM are considered for comparison. These techniques are entirely different from each other so very few design parameters can be used for providing common platform for the purpose of comparison. Table 1 provides the simulation set up used in this work. The common design parameters are FFT size, bits per carrier, modulation order and modulation type. The performance evaluation of the three techniques is done on the basis of PAPR and PSD.

Table I: System parameters for comparison

System Parameter	Value
FFT Size	1024
Bits Per Carrier	2
Modulation Order	4
Modulation Type	QAM

The performance evaluation is done using MATLAB platform.

IV. RESULTS AND DISCUSSION

By using system parameters given in Table I Peak To Average Power Ratio and Power Spectral Density of all three multi carrier modulation techniques have been observed and results are given in Table II.

Table II: Comparison of Various MCM Schemes

Multicarrier Modulation	PAPR(dB)	PSD(dB/Hz)
UFMC	22.4422	0.0452
FBMC	20.9549	0.0093
OFDM	27.7897	0.9318

From Table II it is clear that FBMC is having minimum value of PAPR and PSD while OFDM is showing maximum values of PAPR and PSD. UFMC is having moderate values of both PSD and PAPR.

After doing comparative analysis of all the three techniques we have observed effect of the design parameters (FFT Size, Bits per sub carrier (BPS) and Modulation order) on these multicarrier modulation techniques.

1) Effect of FFT Size: One common design parameter in all three techniques is FFT size. Effect of FFT size can be given as:

a) Effect of FFT on UFMC: Table III is showing the effect of FFT size on PSD and PAPR of UFMC.

Table III: Effect of FFT size on UFMC

FFT Size	PAPR(dB)		PSD(dB/Hz)	
1024	22.4422		0.0452	
512	21.7315		0.1849	
256	19.0779		0.3040	

b) Effect of FFT size on FBMC: FBMC is also having same effect FFT size on PAPR of waveform as were on UFMC but when we saw effect on PSD of FBMC it is minimum at moderate value of FFT points. The effect of different FFT Size on PAPR and PSD of FBMC is given in Table IV.

Table IV: Effect of FFT size on FBMC

FFT Size	PAPR(dB)	PSD(dB/Hz)
1024	20.9549	0.0093
512	14.3302	0.0023
256	11.9462	0.0047

c) Effect of FFT Size on OFDM: Effect of FFT size on OFDM can be observed from Table V. In OFDM when we decrease FFT size PAPR and PSD of system also starts decreasing.

Table V: Effect of FFT Size on OFDM

FFT Size	PAPR(dB)	PSD(dB/Hz)
1024	27.7897	0.9318
512	19.4538	0.5006
256	16.5145	0.5006

2) Effect of Bits per subcarrier (BPS) and modulation order: Other design parameters which are common in all three modulation technique are bits per sub carrier and modulation order.

a) Effect of BPS and Modulation order on PAPR of Multi carrier modulation: Bits per sub carrier (BPS) and modulation order are inter-related to each other when Bits per sub carrier are 2, 4, and 6 at that time modulation order is 4, 16, and 64 respectively. Table VI shows effect of bits per sub carrier on three multicarrier modulation techniques

Table VI: Effect of Bits Per Subcarrier on PAPR of MCM

Bits per Subcarrier	PAPR(dB)		
	UFMC	FBMC	OFDM
2	*22.4422*	*20.9549*	*27.7897*
4	*19.5845*	*28.1118*	*33.4793*

6	*21.4756*	*24.0694*	*35.5123*

It can be concluded that PAPR of UFMC is minimum at Moderate value of bits per sub carrier as well as modulation order. On the other hand, FBMC shows completely inverse characteristics than that of UFMC because it is having maximum value of PAPR at middle values of BPS and modulation order. OFDM is having increasing PAPR with increasing value of BPS and Modulation order.

b) Effect of BPS and Modulation order on PSD of Multi carrier modulation: The 2nd factor which gets affected by these design parameters is Power spectral density. Table VII shows the effect of BPS and Modulation order on all the three modulation schemes.

Table VII: Effect of BPS on PSD of MCM

Bits per Subcarrier	**PSD(dB/Hz)**		
	UFMC	FBMC	OFDM
2	0.0452	0.0093	0.9318
4	0.3910	0.0126	4.2691
6	1.3170	0.5215	19.5700

All the modulation schemes are having same impact of increasing bits per sub carrier and modulation order on their PSD. With increasing BPS their PSD also starts increasing but the maximum change was observed in OFDM system.

V. CONCLUSION AND FUTURE SCOPE

In this work, the main factors influencing the Peak To Average Power Ratio and Power Spectral Density has been carefully studied for three multicarrier modulation techniques. It can be concluded that UFMC is having moderate Peak to Average Power Ratio and Power spectral density which seems to be nearly equal to FBMC while having very less system complexity. So, UFMC looks pretty suitable for next generation wireless communication systems. Like other modulation techniques, UFMC also suffers from the limitation of high PAPR so in future we will focus on implementing some effective PAPR reduction techniques for UFMC.

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