FBMC and UFMC: The Modulation Techniques for 5G

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***Abstract*—Orthogonal-Frequency-Division-Multiplexing (OFDM) is a promising multicarrier-modulation-technique and is an eminent alternative for the fourth-generation wireless communication system (4G), as it offers high spectral efficiency, multipath propagation, the frequency selective fading channels are protected and efficient power efficiency. Yet, OFDM is certainly not a right contender for 5G as it isn't fit for supporting the various applications 5G is going to offer and 4G wireless communication techniques go through from the limitations of High Peak-to-Average-Power-Ratio (PAPR), Cyclic Prefix (CP) and sideband leakage is another limitation of OFDM.**

Objectives: Our intention is to design an innovative waveform having great spectral-efficacy and less PAPR for 5G Wireless-Communication System. Techniques /Analysis: In this paper, distinctive subcarriers and QAM regulation methods are used to evaluate the PAPR of numerous multicarrier modulation techniques like OFDM, Filter Bank Multicarrier Modulation (FBMC), Universal Filtered Multicarrier (UFMC), etc. Findings: Because of the presence of CP, the spectral-efficacy of OFDM is poor rather than the FBMC and UFMC and consequently can be enriched by FBMC and UFMC. CP can also be eliminated by making use of the independent filters for individual subcarriers and intensification in the subcarriers moderates the PAPR further. Improvements: On comparing various multicarrier modulation techniques like OFDM, FBMC, UFMC, etc. It is concluded that UFMC is an improved waveform technique for future wireless communication technique (5G) having less PAPR and PAPR can be additionally diminished by applying the optimization procedures.

Keywords: OFDM, FBMC, UFMC, PAPR, CP QAM.

I. Introduction

OFDM is the utmost prevalent multi-carrier-modulation-technique which is being utilized in the present generation of wireless-communication [1]. In OFDM the used spectrum is divided into narrow sub-bands. Separate data is transmitted in each band using different carriers that are orthogonal to each other [2]. But in the former few years, the need for increasing data rates and the total number of users has been increased exponentially. So, next-generation wireless communication systems must be capable to deal with an enormous number of customers [4] and provide a much higher-data-transmission-rate using a less complex system. Thus, different new multi-carrier-modulation-techniques like FBMC, UFMC, and GFDM (Generalized-Frequency-Division-Multiplexing) have been developed [1][3] to accomplish all these necessities.

FBMC is a pioneering method of OFDM which uses arrays of filters at the transmitter and receiver but does not make use of the CP. The benefit of this scheme is that it gives effective and improved results than OFDM without using CP. Subcarriers are sifted independently and give vigor against inter-carrier-interference (ICI) impacts in FBMC [4][5]. However, FBMC schemes make use of filters, whose interval is several times of samples per multi-carrier symbols and results in amplified complexity of the organization. UFMC is the prime and a new multi-carrier modulation method for the upcoming generation of wireless communication system, which incorporates the attributes of FBMC and OFDM. Instead of per subcarriers like FBMC, the entire signal is filtered in a single go like OFDM, groups of subcarriers are filtered in UFMC. This permit diminishing the length of filter considerably in comparison to FBMC. So, it is less complicated like OFDM and supports improved subcarrier separation like FBMC. The foremost complication of all the multicarrier modulation schemes is high PAPR [6] [9][10].

II. FBMC

FBMC is the dynamic technique for OFDM that doesn't use CP yet uses just varieties of signals and FBMC filters each subcarrier-regulated signal in a multicarrier system. The model filter is balanced for the zero-frequency carrier and is the establishment for valuable subcarrier filters. The filters are recognized by the relating component L, where L speaks to the quantity of multi-carrier symbols that overlap in the time-space. The first signal order is given as 2*L-1 where L

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= 2, 3, or 4 and is embraced according to the PHYDYAS plot
[3][5].

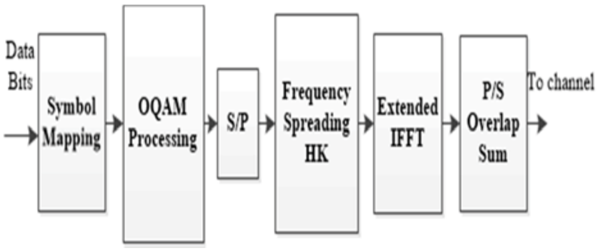

Fig. 1. FBMC- Transmitter block illustration.

The receiver-end operation is given in the figure below.

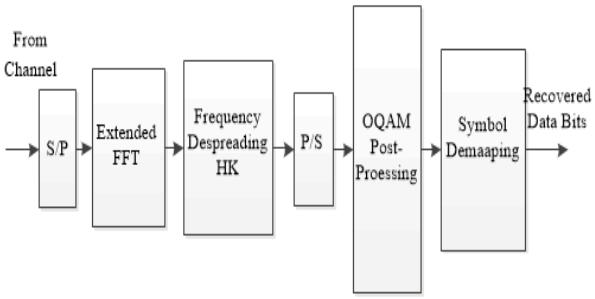

Fig. 2. FBMC Receiver block diagram

The rudimentary FBMC demodulator which additionally measures the BER for the selected arrangement when the channel is missing is shown in Fig. 2. To get the received data streams, the processing incorporates composed filtering sought after by QAM separation. The data streams received are de-mapped to bits and the resultant BER is resolved to rectilinear multi-tap equalizers and is utilized to moderate the properties of frequency-selective fading in presence of a channel.

III. UFMC

UFMC is considered one of the best and original multicarrier modulation methods for 5G and it is based on FBMC and OFDM. In this scheme, a filtering process is carried out on a group of sub-carriers in contrast to self-subcarrier modulation in FBMC. The filter-length compared with the FBMC is reduced by subcarrier grouping and the modulation time is also reduced. The UFMC transmitter block diagram is demonstrated in fig. 3. In this scheme, the total bandwidth is initially disseminated into a number of sub-bands and is allocated to the number of subcarriers. Each sub-band has k subcarriers. The time-domain of the signal is changed to a frequency domain at the transmitter by the N-point IFFT operation. IFFT action confirms that the sub-band carriers don't interfere. The output of the filter bank is written as

$$x_k = \sum_{i=1}^{B} F_{i,k}, V_{i,k}, S_{i,k} \qquad (1)$$

Where $S_{i,k}$ signify data streams

$F_{i,k}$ signify Chebyshev filter

$V_{i,k}$ signify IFFT to eplitz matrix

$$F_{i,k} = \frac{\cos\left\{ M \cos^{-1}\left[\beta \cos\left(\frac{\pi k}{M} \right) \right] \right\}}{\cos\left[M \cosh^{-1}(\beta) \right]}$$

K= 0, 1, 2, …M-1 (2)

$$\beta = \cosh\left[\frac{1}{M} h^{-1\left(1_{0^{\alpha}}\right)} \right], = 2, 3, 4$$

Where α signifies diminution of the adjacent lobe. The type of modulation used by the UFMC is QAM.

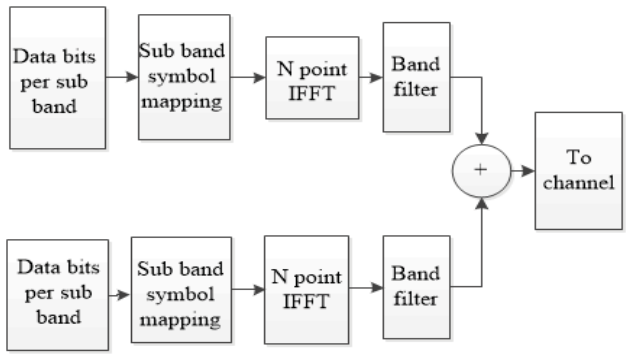

Fig.3. represents the UFMC transmitter-block- diagram.

In order to perform a Chebyshev filtering operation, UFMC makes use of the Band-filter. Band filter sums up all the sub-band responses and also filters all sub-band.

The UFMC receiver block diagram is demonstrated in fig. 4. The information that is received from the channel is given to the sequential to parallel converter and furthermore 2N point FFT is performed by the UFMC receiver on the information to demodulate it. A guard interim of zeros is included between progressive IFFT streams. And hence due to Transmitter filter delay, the Inter-Symbol-Interference (ISI) is prevented.

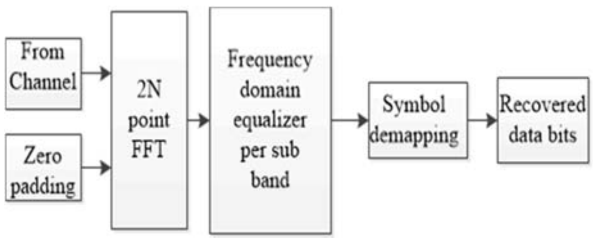

Fig. 4. UFMC receiver block diagram

FFT is performed at the receiver and hence converts the frequency domain to the time domain. In order to convert the streams into bits and retrieve the original information, the symbol de-mapping is executed.

Table I: shows the Comparative Characteristics of Multiplexing Techniques

Signal processing methods	Multiplexing features		
	Method of filtration	Filter length	Frequency orthogonality
OFDM	Whole band	≤ CP duration	Orthogonal
FBMC	Subcarrier	= (3,4,5) × symbol duration	Orthogonal in the real part
UFMC	Subrange	= duration of CP	Orthogonal

IV. PAPR

UFMC has diverse benefits over other modulation techniques, but it also has many disadvantages like high PAPR [6][9]. The PAPR is depicted as the extent of the pinnacle capacity $y[n]$ to its normal power. PAPR occurs when the dissimilar sub-carriers are not in phase with one another in a multicarrier framework. In a multi-carrier framework, there is an immense number of individually modulated sub-carriers which are dissimilar with respect to one another at various phase-values. Once the extreme value is achieved by all the subcarriers simultaneously, this causes the output to envelop to instantly increase which generates a 'peak' in the output, and it gives a large peak value which is very large in comparison to the average value of the sample, when they are added up together in a well-organized manner for transmission purpose. The mathematical evaluation of PAPR is given in equation (4)

$$PAPR = 10\log_{10}\frac{Maximum\left\{\left|y[n]\right|^2\right\}}{Expectation\left\{\left|y[n]\right|^2\right\}} dB \qquad (4)$$

Where $E\{.\}$ expresses the expectation operation. Additionally, for the FBMC/OQAM signals, the CCDF of PAPR gives the likelihood P_r that PAPR is above numerous threshold levels (γ) can be expressed as

$$CCDF(\gamma) = P_r\left(PAPR\left(y[n]\right) > \gamma\right) = 1 - \left(1 - e^{-\gamma}\right)^k$$

(5)

In order to reduce the PAPR, various methodologies have been suggested. These methodologies can be mainly characterized into two groups viz. signal scrambling methods and signal distortion methods [6]. Signal scrambling techniques are all variants in what way to scramble the codes to diminish the PAPR. Coding methods are used for signal-scrambling. The overhead corresponding to the comprehensive examination of the finest code would rise exponentially with the intensification in the number of carriers. Both In-band and Out-of-band interference and intricacy to the framework are introduced by the signal distortion methods, and high peaks are directly reduced by the signal-distortion procedures by contorting the signal before intensification. Clipping the FBMC/UFMC signal afore amplification is the least difficult technique to confine PAPR. Yet, clipping causes enormous Out-of-Band (OOB) and In-Band interference, resulting in the degradation of system performance. The fundamental need for functional PAPR reduction methods incorporates the similarity with the group of officially existing modulation schemes, high spectral effectiveness, and low complexity includes the compatibility with the family of already existing modulation schemes, high spectral efficiency, and low intricacy. SLM is one of the probabilistic techniques that is implemented to diminish the PAPR of FBMC and UFMC signals. It is termed as Probabilistic technique because the probability of the existence of high PAPR is focused by modifying the signal. Hence, reduction in PAPR without contorting the signal can be achieved by SLM and furthermore it won't cause any loss to the data. The main shortcoming of SLM is that it has high complexity.

V. SIMULATION RESULTS

The whole band of the system is distributed into 10 sub-bands where individual sub-band has 20 subcarriers with very few side lobes. For 200 subcarriers the Power Spectral Density values can be seen from fig. 5 and fig. 6, and on comparing the fig. 5 with fig. 6 it can be seen that UFMC makes better use of spectrum than FBMC. Table II gives the comparison of different mapping techniques using MATLAB simulation. From simulation results, it can be seen that as the total number of bits per subcarrier increase, the BER of UFMC increases**.** Also. from Table II, PAPR and BER values of the UFMC system are low in comparison with the FBMC.

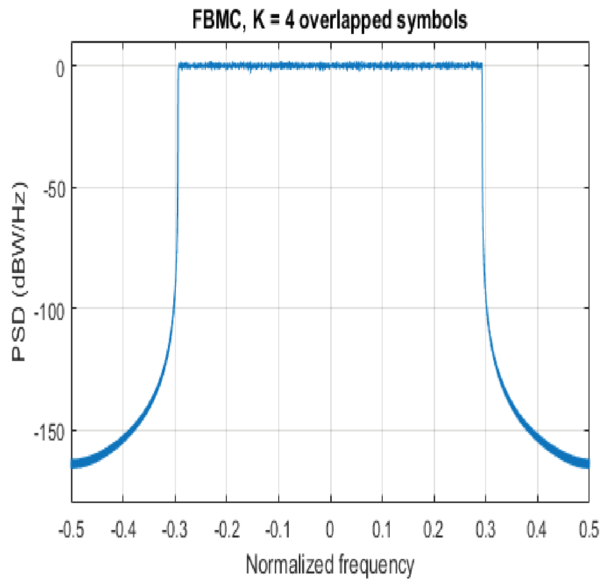

FIG.5. PSD OF FBMC

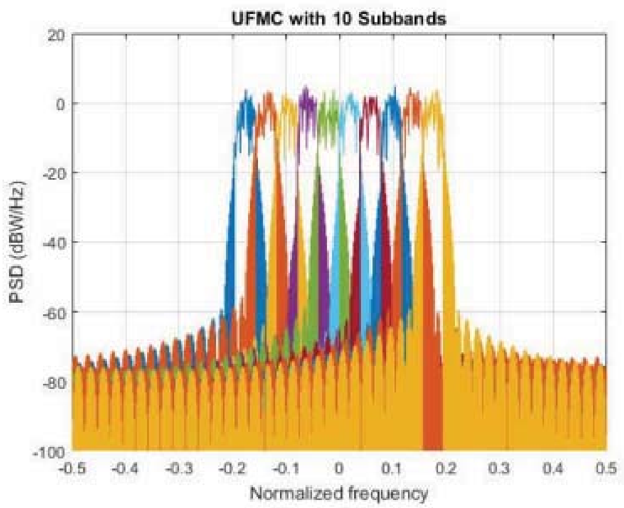

Fig.6. PSD of UFMC

Table II: Comparison of BER and PAPR of FBMC and UFMC

Modulation Techniques	Bit Error Rate (UFMC)	Peak to Average Power Ratio (UFMC)	Peak to Average Power Ratio (FBMC)
4QAM	0.23	6 dB	7.8 dB
16QAM	0.7	5.5 dB	7.4 dB
64QAM	0.8	4.9 dB	7.2 dB
128QAM	0.9	4.6 dB	7 B
256QAM	0.95	4.3 dB	6.8 dB

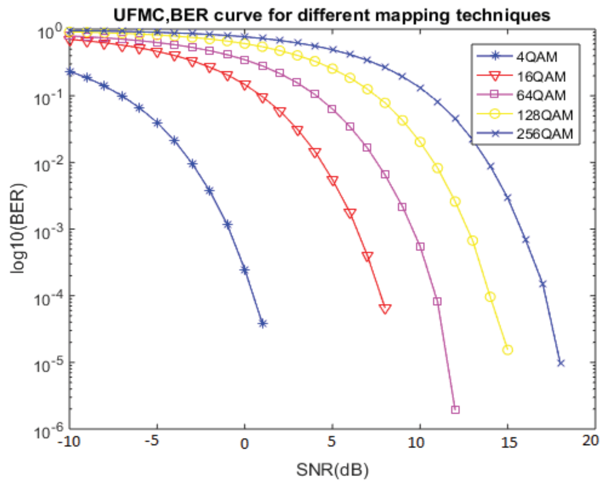

Fig.7. BER performance of various mapping/modulation techniques for UFMC.

VI. CONCLUSION

The present wireless communication system (4G) undergoes various limitations like PAPR, low spectral efficiency, etc. These limitations are addressed by FBMC and UFMC, which are both the promising waveform candidates for the 5G wireless communication system. 10% of the bits are repeated in OFDM with the use of CP in OFDM, whereas CP is not used in UFMC, which results in the increase of spectral efficiency. The overall band in UFMC is distributed into sub-bands. As the total number of sub-carriers that are added up in phase will be less in UFMC the most extreme power diminishes in UFMC and this results in better PAPR for UFMC. The BER execution of UFMC gives 0.23dB using 4QAM and 4QAM modulation technique is better when compared with other modulation techniques. 256QAM modulation method gives better PAPR value for UFMC technique.

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