
A study of the effect of Windows Filter on PAPR of Universal Filtered Multicarrier Modulation

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ABSTRACT

In this paper Orthogonal Frequency Division Multiplexing Modulation (OFDM) was studied and the problems associated with it was highlighted in UFMC sub-band modulation, which was presented as a suitable for 5G waveform. This problems associate with the Peak to Average Power Ratio (PAPR) on OFDM were discussed using results from UFMC simulation obtained with the three (3) filter windows differently to analysis the performance to determine lowest PAPR utilization in UFMC sub-band filters. The result obtained shows that the Bohwin window produced the lowest PAPR value compared to chebvev and Bartlett, also in the overall performance UFMC shows better performance compared to OFDM in terms of PAPR and ability to carry higher data rate.

Key words: Orthogonal Frequency Division Multiplexing Modulation, Peak to Average Power Ratio,

INTRODUCTION

The 5G applications includes multiple gigabyte connection, uses ultrahigh broadcast frequency, vehicle to vehicle pairing and Internet of things high speed applications for multimedia etc. with the current global internet connections of things than people and industrial equipment connection of peer to peer connection, Appliances security systems, health monitor, door locks, educational network etc (Gerzaguet *et al.*, 2017). but still limited to the capability in handling high data rate with wide bandwidth, the issue of very low latency for data bursts either short of long, consideration for transmission time intervals which is needed to be short and fast switching between downlink and uplink are important requirements for any modulation scheme that will support 5G communication system (Melki *et al.*, 2019). And for low data rate devices, the possibility of energy efficient communication system by reducing the on-times for low data rates transmission. These are the requirements that for 5G waveforms for the needed facilities.

REVIEW OF RELATED WORKS

Several new forms of OFDM have been proposed for 5G applications, such as CP-OFDM, F-OFDM, W-OFDM, GFDM, UFMC, and FBMC. The need for more robust multicarrier modulation scheme for higher data rates the bandwidth spectral efficiency is the motivation for the development of filtered multicarrier modulation scheme(Gerzaguet *et al.*, 2017). Orthogonal frequency division multiplexing has been an excellent waveform choice for 4G (Kaltenberger *et al.*, 2015).

It provides outstanding spectrum efficiency, it can be managed and controlled with the processing levels attainable in current mobile handsets, and it operates well with high data rate

stream occupying wide bandwidths. It operates well in circumstances where there is selective fading. It is expected that by the official rollout of 5G in 2020 many more waveform will be tested to ensure which meets the requirement for 5G standards or data transmission (Fan *et al.*, 2017). OFDM the multicarrier modulation scheme is the major backbone of 4G LTE systems and definitely OFDM variants with filtering addition are the possibility of 5G waveform. (van Nee & Prasad, 2000), OFDM requires the use of a cyclic prefix and this occupies space within the data streams. There are also other advantages that can be introduced by using one of a variety of new waveforms for 5G. OFDM, orthogonal frequency-division multiplexing. OFDM decomposes the transmission frequency band into a group of narrower contiguous sub bands (carriers), and each carrier is individually modulated. Such a modulation can be simply realized by an inverse fast Fourier transform (IFFT) (Melki *et al.*, 2018). The advantage OFDM gains in being effective over frequency selective fading channels is that its use of orthogonal subcarriers helps eliminate subcarrier sub-talk At the receiving end, the OFDM signal can be demodulated with a Fast Fourier Transform (FFT) and easily equalized with a complex gain at each subcarrier (Melki *et al.*, 2018; Yi, 2018).

OFDM uses cyclic prefix, which refers to the prefixing of a symbol with a reiteration of the end. The CP serves two purposes in OFDM transmission it serves as Guard interval to eliminate ISI from the earlier symbol the typical receiving end of the OFDM is configured to eliminate the cyclic prefix samples (Bahai *et al.*, 2004). If In a frequency selective multipath channel is to be modelled as a circular convolution and transformed to frequency domain using DFT effect of ISI due to the repetition at the tail end of the symbol needs to be tackled using CP (Cho *et al.*, 2017). This method permits for simple frequency-domain handling, such as channel estimation and equalization. In order for the cyclic prefix to function as its above-mentioned objectives, the length of the cyclic prefix least must equal the length of the multipath channel (Geng *et al.*, 2015).

OFDM has popularized the concept of cyclic prefix, cyclic prefix is also now also used in single carrier systems to progress the robustness to multipath propagation as it helps to alleviate ISI (Schaich & Wild, 2014). Some of the problems associated with OFDM are, High PAPR, The Waveform of OFDM is not spectrum localized out-of-band leakage rejection requirement need about 10% guard band, OFDM waveform is not flexible, OFDM has fixed subcarrier spacing & limited number of cyclic CP, OFDM waveform cannot support asynchronous operation Timing adjustment is needed. The spectral efficiency is poor in OFDM due to the presence of cyclic prefix and the efficiency can be improved by FBMC and UFMC.

Other disadvantages of OFDM has to do with certain constraints like cyclic-prefix overhead, Sensitivity to frequency offset CFO, Spectral re-growth and High PAPR makes it not the most reasonable waveform for all the focused on applications of 5G (Schaich *et al.*, 2014; Singh, 2018)

METHODOLOGY

This research was carried out by first creating OFDM using MATLAB-Simulink and passing it through three different filters (windows filter namely Chebyshev window, Bohman window and Bartlett window) for performance evaluation as means of validation.

The codes used for this research is adopted from math work with modification made by using three window filter. In coding the transmitter the following steps were followed;

- i. QAM Symbol mapper

- ii. Transmit-end processing
- iii. Initialize arrays
- iv. Loop over each sub-band
- v. Pack sub-band data into an OFDM symbol
- vi. Filter for each sub-band is shifted in frequency
- vii. Plot power spectral density (PSD) per sub-band.

While for the receiver the following steps were followed

- i. Add WGN
- ii. Pad receive vector to twice the FFT Length
- iii. No windowing or additional filtering adopted
- iv. Perform FFT and down sample by 2
- v. Select data subcarriers
- vi. Plot received symbols constellation
- vii. Use zero-forcing equalizer after OFDM demodulation
- viii. Equalize per sub-band - undo the filter distortion
- ix. Plot equalized symbols constellation
- x. De-mapping and BER computation
- xi. Perform hard decision and measure errors
- xii. Restore RNG stat

UFMC and Filtered-OFDM

The advantage UFMC possesses is that due to grouping of Sub-band we are able to reduce the filter length used in filtering. The system bandwidth is divided into sub-bands and filtered individually, and then each sub-band can be ordered with different waveform parameters set according to the actual traffic scenario. Through the filter arrangement, each sub-band would achieve its own configuration, and the combined 5G waveforms would supports dynamic soft parameters configuration for air-interface according the traffic types.

Table 1: LTE and 5G modulation types

<u>Modulation</u>	
OFDM	The entire band is filtered in filtered
FBMC	Individual subcarriers are filtered
UFMC	While groups of subcarriers (sub-bands) are filtered

UFMC has more spectral efficiency compared to OFDM. There is no cyclic prefix insertion like in OFDM, Also, UFMC can still use QAM as it retains the complex orthogonally (when compared with FBMC), which works with existing MIMO schemes. As stated earlier the total band of Subcarriers N is split into sub-bands, Therefore each Sub-band is made up of a number of Subcarriers however not all sub-bands is required for a given transmission An N-point IFFT for each sub-band is computed, inserting zeros for the unallocated carriers.

The most distinct part of UFMC is the filtering that is applied to each sub-band. The Sub-band is filtered with filter length L and the total responses from the sub-bands are added. The filtering is done to reduce the out-of-band spectral emissions. Different filters per sub-band can be applied, however, in this paper; we will use the same filter for each sub-band.

This current implementation is different from the traditional CP OFDM in that cyclic prefix is not used, but a zero-postfix is used in flushing the filter. The same filters are used for each band; however, to keep to the same sub frame lengths as obtainable in LTE, two filters of dissimilar lengths are used.

For the i th sub-band the data blocks represent with $S_{i,k}$, IFFT matrix with $V_{I,K}$ and filter with $F_{I,K}$. The output of filter bank is shown in equation (1)

$$x_k = \sum_{I=1}^B F_{I,K} \cdot V_{I,K} \cdot S_{i,k} \quad (1)$$

Where $S_{i,k}$, k represents data blocks

Note that the filter response of the sub-band are pre-compensated so that from the transmitter allowance for existing techniques for channel estimation can be used at the receiver end. The effect of this is the reduction in the complexities of the UFMC receiver. The receive FFT order engaged is the same as that used at transmitter. The postfix filtered tail samples are added to the main symbol body for FFT processing. On the receive end, the channel estimation and MIMO processing are the same as that used for CP-OFDM LTE.

Windows are majorly used to tackle the effect called Gibbs phenomenon which is caused as a result of truncation of an infinite Fourier series. When a function as a Fourier series has a jump continuity and jumps in the middle of a Fourier series the estimation will end up overshooting the Jump. The overshoot doesn't go to zero irrespective of how many terms we add to it except infinite terms which practically we can't. This is the effect of Gibbs phenomenon. This means if an algorithm approximates a function by its Fourier series and that function experiences a jump discontinuity the Fourier series will introduce artifacts into its estimation.

Choice of Windows function is a very significant in ensuring the overall output of a signal is of good quality.

Peak to Average Power Ratio

In multicarrier modulation like OFDM we usually measure two power levels namely peak power and average power. The occurrences of PAPR multicarrier transmission systems is due to the fact that the different sub-carriers which are out of phase with each other. These Multicarrier are IID but due to central limit theorem tends to have a normal distribution which forms a peak at the center and hence, when maximum value is achieved simultaneously by all points; there will be sudden upsurge in the output and this will cause a peak. The power spikes is where we measure the peak power level from OFDM has a disadvantage of relatively high PAPR In Modulation schemes such as OFDM transmitter time domain signal will have higher PAPR, which leads to various distortions in the transmitter chain and degradation of system performance i.e. BER/PER. Also requires highly linear power amplifier which increases cost of the system

$$PAPR = \frac{PeakPower}{AveragePower} \quad (2)$$

Taking the ratio of peak power to average power of time domain complex baseband signal which is to be transmitted we get the PAPR of the received signal. High PAPR is not favorable to our system as mentioned above because it increased the power prerequisite of our amplifier and most typical system powered by batteries will suffer drain.

This are the down side of this high PAPR especially that the power amplifier in the transmitter is operated at a relatively lower power level so that the peaks in the signal are not distorted by the saturating amplifier. This is called the amplifier back off and it plays an important part in wireless system design.

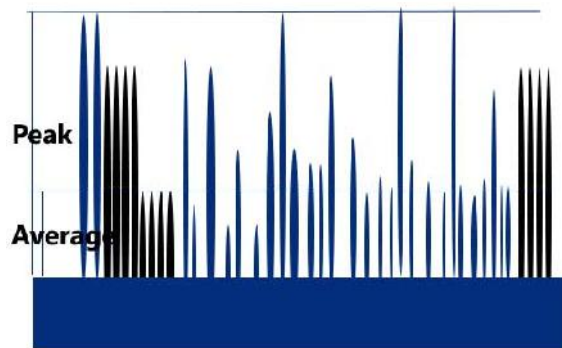


Figure 1. Peak to Average Power Ratio

The reason for this high PAPR is that when multiple sinusoids are summed together in a multicarrier transmission the resultant signal displays profitable and unhelpful behaviour. The higher the number of these sinusoids higher is the PAPR.

Chebyshev Window Design

The Chebyshev window minimizes the main lobe width, given a particular side lobe height. It is characterized by an equiripple performance, that is, its side lobes all have the same height. As shown in Figure 2, the Time Domain plot, the Chebyshev window has large spikes at its outer samples.

Chebyshev filters also utilize a polynomial for approximating the filter transfer function. They provide a sharper roll - off than Butterworth filters, but at the expense of a ripple in the passband. 2 Chebyshev filters are described by the transfer function $G(s)$ as in equation (3)

$$|G(s)|^2 = \frac{K}{1 + \varepsilon^2 T_N^2\left(\frac{s}{\Omega_c}\right)} \quad (3)$$

Ω_c = cut-off frequency

T_N = Chebyshev polynomial of the nth order

ε = ripple factor

Chebyshev filters have the property that they reduce the error between the idealized and the actual filter characteristic over the range of the filter, but with ripples in the pass band.

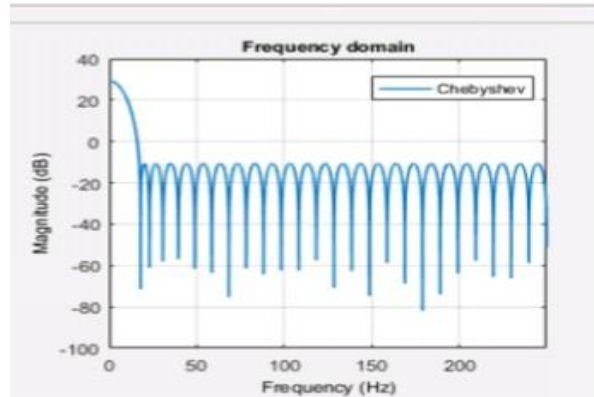


Figure 2: Chebyshev window designer

Bohman Window Design

Syntax `w = bohmanwin (L)`

Description `w = bohmanwin (L)` returns an L-point Bohman window in column vector `w`. A Bohman window is the convolution of two half-duration cosine lobes. In the time domain, it is the product of a triangular window and a single cycle of a cosine with a term added to set the first derivative to zero at the boundary. Bohman windows fall off as $1/w^4$.

To compute a 64-point Bohman window.

`L = 64; bw = bohmanwin (L); wvtool (bw)`

The equation for computational the coefficients of a Bohman window is stated in equation

$$W(x) = (1-|x|\cos(\pi|x|) + \frac{1}{f}\sin(f|x|)) \quad (4)$$

For $-1 \leq x \leq 1$

Where `x` is a length-L Vector of linearly spaced values generated using line space function in MATLAB. The first and last elements of the Bohman windows are forced to be identical zero

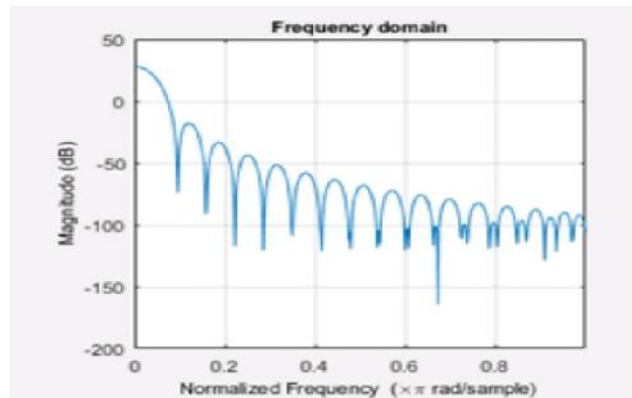


Figure 3: Bohman window designer

Bartlett Window

The coefficient of a Bartlett windows are computed using equation (5). The Bartlett window

is very similar to a triangular window as returned by the triangle function. The Bartlett window always has zeros at the first and last samples, however, while the triangular window is nonzero at those points. For L odd, the centre L-2 points of Bartlett (L) are equivalent to triangle (L-2)

$$W(n) = \begin{cases} \frac{2n}{N} & 0 \leq n \leq \frac{N}{2} \\ 2 - \frac{2n}{N} & \frac{N}{2} \leq n \leq N \end{cases} \quad (5)$$

Where Syntax w = Bartlett (L) [7]

Description w = Bartlett

(L) Returns an L- Point Bartlett window in the column vector w, where L must be a positive integer.

W= Bartlett (L) returns an L-point Bartlett windows in the colum vector w where L must be a postitive integer.

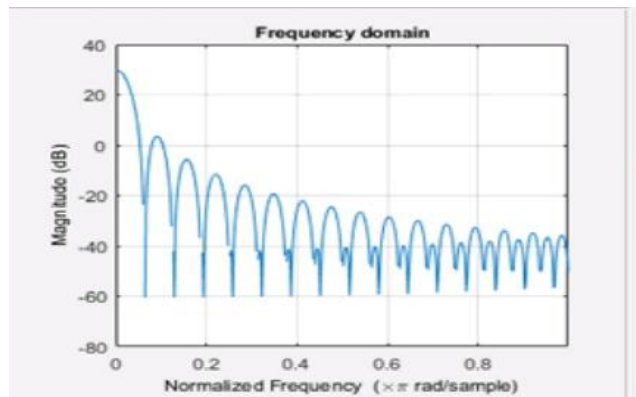


Figure 4 Bartlette window designer

RESULTS AND DISCUSSION

Simulation results shows the various sub-band responses based on different window function used and graphs of PSD against normalized frequency plotted. As can be observed from the plot the Bohwman window demonstrates side lobes suppression better Figure 6.

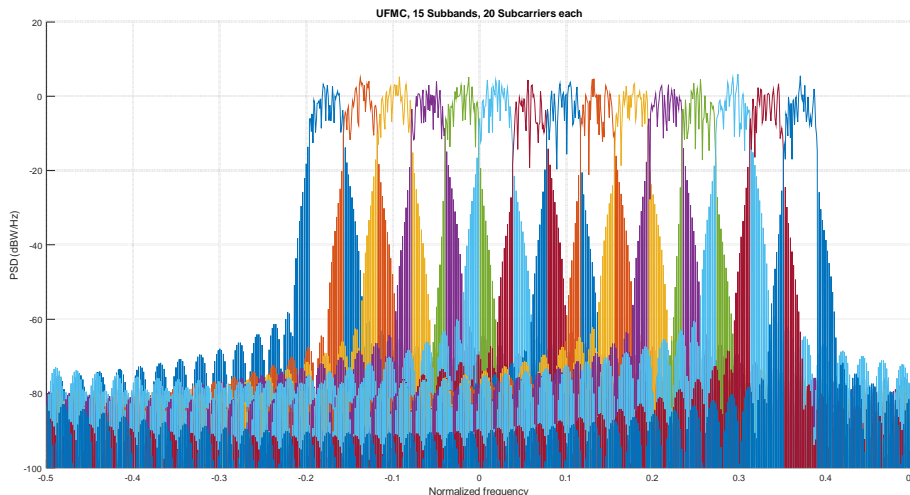


Figure 5: UFM modulation using Chebyshev window filter

From Figure 5, it can be observed that the average level of side lobes of the Chebyshev was between 88db-60db and the effect of gibbs phenomenon can be seen. Higher side-lobe levels are associated with a narrower main lobe and more continuous endpoints.

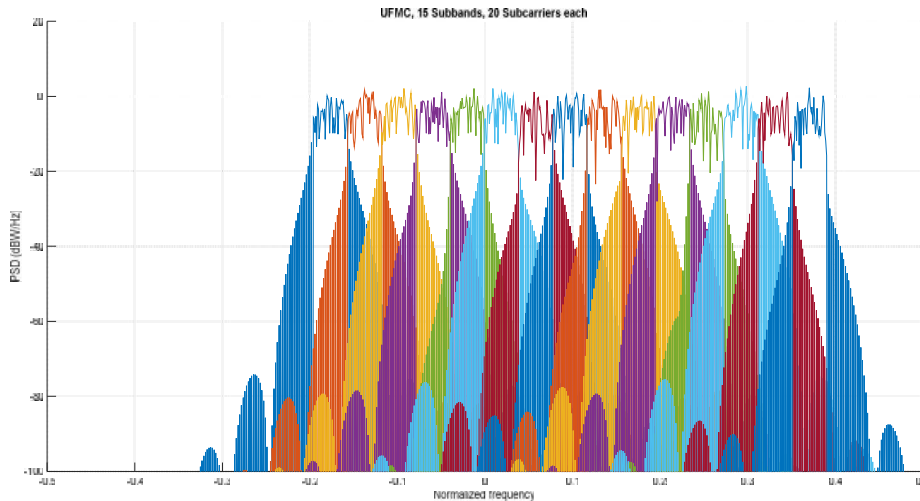


Figure 6: UFMC modulation using Bohman window filter

From Figure 6, shows the Bohman window, The Bohman window is the convolution of the sine window with itself. It can be observed that the average level of side lobes of the bohwmn windows was between 90db-80db and the effect of gibbs phenomenon can be seen but at a much lesser rate. This appears a better side lobe suppression than the previously studied chebshev window.

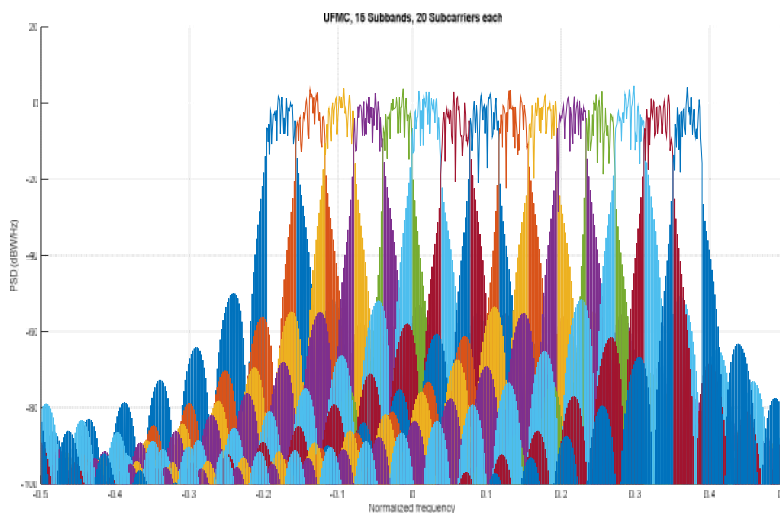


Figure 7: UFMC modulation using Bartlett window filter.

The Bartlett window is a triangular window is the 2nd order *B*-spline. The figure shows side lobes as well and observation can be made to conclude that this side lobes also consume considerable energy from the main carrier.

Table 2: PAPR results

Window Method	PAPR
Bohwin	7.628 dB
Chebyshev	7.9407 dB
Bartlett	7.8802 dB

CONCLUSION

In this paper, 15 sub-band, 20 subcarrier each UFMC was simulated using three different windows. The PAPR using Bohwin window was lowest. The results shows that even though the three produced 5G compactible waveform, and the PAPR values produced by the filters utilized are close, using the Bohwin window gives us the lowest PAPR .This also shows that carefully designed window filters can actually have noticeable impact on PAPR of multicarrier modulation scheme.Future work can test other windows filter to check their impact on PAPR like the modified Dolph-Chebyshev, Poisson, Hann-poisson, Blackmann, Harris-Nuttal etc

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