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An Assessment of Performance Evaluation of Filtering Techniques in OFDM

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Abstract: *Filtered orthogonal frequency division multiplexing is one of the most promising candidate waveform for the upcoming wireless communication system. Filtered OFDM ensures all the advantages of the orthogonal frequency division multiplexing technique with additional advantages in terms of spectrum efficiency and robustness in high SNR system and also in some specific cases, ideal spectrum utilization can be achieved by OFDM which can completely eliminate the guard band. This paper aims at comparing the performance of various filters by different windowing techniques such as rectangular, triangular, bartlett and hanning window to complex window function such as kaiser, nuttall'sblackman-harris, root raised cosine window which can be applied to OFDM in terms of spectrum confinement, BER improvement and overall throughput betterment. In this research work, multiple windowing techniques have been simulated with Filtered OFDM and their performance has been evaluated. Based on the simulation results, OFDM with complex window function such as kaiser, nuttall'sblackman-harris, root raised cosine can be seen as the potential candidate for future generation wireless communication system in terms of betterment in spectrum efficiency and improved out of band interference.*

Keywords: *Wireless Communication, OFDM, windowing techniques, root raised cosine window, Kaiser Window, nuttall's blackman-harris window.*

1. INTRODUCTION

Fifth generation mobile communication system is the upcoming phase after the 4G LTE that is long term evaluation standards. 5G technology should not be limited only for the mobile communication system but it will cover almost all the sectors such as various industries, semiconductor vendors, various manufacturing firms any many more. 5G will reach not only specified for cell phones but it will reach to almost all industries. Huge demand for wireless based services such as to carry video and other rich content services and IoT (internet of things) based services are the major push toward the race to fifth generation technology. To fulfil this major objectives next generation technology will provide large broadband speed, ultra reliable connectivity and ultra-low latency for minimum delay in the communication.

In order to improve the data rate and spectral efficiency we can depart physical layer of 5G from 4G LTE in number of ways. Coding Schemes, channel models, power amplifier design, modulation schemes all need to be designed and developed according to meet the 5G standards. To improve spectral efficiency by limiting out-of-band emissions new radio waveforms including: Filtered OFDM (F-OFDM), Windowed OFDM (W-OFDM), and Cyclic Prefix OFDM (CP- OFDM) is proposed by the3GGP.

2. SYSTEM MODEL

OFDM, as a multi carrier modulation technique, has been widely adopted by 4G communication systems, such as LTE and WiMAX. It has many advantages: robustness to channel delays, single-tap frequency domain equalization, and efficient implementation. But the main limitations of this technique in spite ofSeveral advantages are the loss in spectral efficiency due to higher side lobes and the strict synchronization requirements. New modulation techniques are, thus being considered for 5G communication systems to overcome some of these factors. [8]

A new waveform in 5G should be able to support diverse service and deployment scenarios in a carrier band and provide very good spectrum localization, while inheriting the advantages of OFDM. Further justifying these benefits in this document some preliminary analysis is done with the prime contenders for the next generation mobile communication waveform. Waveform candidates for considerations can be roughly categorized in as OFDM based orthogonal waveform as Universal-Filtered (UF-OFDM), windowing-OFDM, and filtered- OFDM belong to this category, in which complex-domain orthogonally of OFDM symbols is maintained [6].

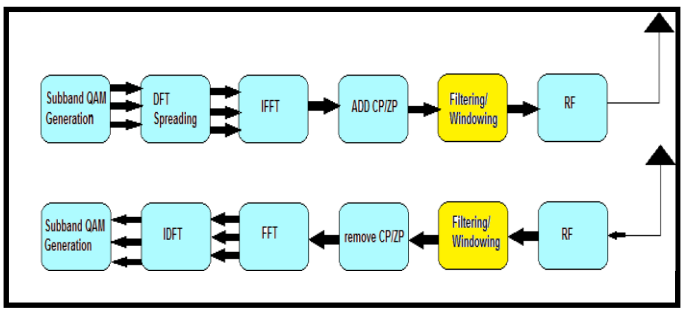

Fig. 1: Block Diagram of OFDM-based orthogonal waveform scheme

Table 1: OFDM-based orthogonal waveform schemes

Category	waveforms	DFT spreading	Prefix	Frequency localization scheme
OFDM based multi-carrier	UF-OFDM	No	ZP	Sub-band filtering
	windowing OFDM	No	CP	Windowing
	f-OFDM	No	CP	Sub-band filtering

Because of the following advantages of filtered OFDM over other waveform contenders we have selected it for the further implementation of designing the next generation waveform.[6]

- Filtered OFDM supports the dynamic configurations to enable mixed service application and various deployment scenarios where each sub-band can serve its own target application or deployment, while the mutual impacts is greatly minimized.
- Filtered OFDM waveform can be easily adapted to support RAN slicing and hence provides a future proof design within a carrierband.
- It maintains the complex-domain orthogonality within the sub-band as OFDM waveform, and hence inherits all benefits of OFDM and could reuse all the OFDM transmitter and receiver schemes.
- Due to the orthogonalityof the waveforms it is much more amicable to MIMO as well as Massive MIMO for the futuretechnologies.
- F-OFDM shows better out-of-band radiation performance, so it can enable very high spectrumutilization.[7]

3. SYSTEM DESIGN

The current 4G LTE standard is centered around traditional OFDM structure with 1024 FFT size, 64 QAM modulation technique with 600 subcarriers over the AWGN medium with 18dB of SNR. The following snapshots are the simulation results of the aforementioned system i.e. 4G LTE with simple OFDM structure.

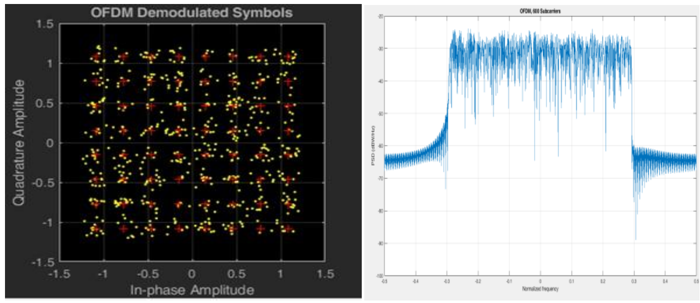

Fig. 2: Constellation and PSD of OFDM system.

From the above results it can be easily identified that there is a huge scope of further improvement in terms of the increment in spectral density by removing out of band emission and also the decrement in BER as per the constellation diagram where in 64 points are quiet scattered.

To improve the performance of the existing scheme, the signal generated after inverse FFT (IFFT) will be divided into number of resource blocks (RBs) and then applied to a specific window / filter with a typical pass band that has:

Sharp transition
Flat characteristics in the pass band High out-of-band rejection

Such characteristics form the base of F-OFDM system wherein to separate one band of frequencies from the other, Windowed-sinc filters are used. The basic properties of windowed sinc functions are: they are very stable, the performance of filter can be increased by minor mathematical changes and computational speed can be increased by changing the order of FFT. To meet above criteria a filter with rectangular frequency response such as sinc impulse response can be used, but sinc impulse response is not causal in nature so windowed function can be used which limits the non-causality and it ends to zero at both the ends and hence offers smooth transition. The ideal filter response for F-OFDM can be constructed by the implementation of various Windowedfunctions.

In first phase of this research work, it has been proven that filtered OFDM technique with basic filtering/windowing aspect will be the better contender over current 4G LTE with traditional OFDM that leads towards the development of one of the blocks of upcoming 5G systems. Moreover in the second phase, with the implementation and analysis of different windowing techniques in the F-OFDM itself, still further improvement in the filter characteristics can be obtained which can decide the appropriate window function for 5G system.

The following section illustrates the simulation results for the realization of F- OFDM technique with multiple windowing techniques which clearly shows the improvement in the above discussed parameters wrt traditional OFDM technique that has been shown in figure 2.

4. SIMULATION RESULTS

In this evaluation, we apply different windowing techniques and based the results obtained; the appropriate window function can be selected that will be suitable for the OFDM.

[1] Rectangular Window:

Here the simulation is carried out by considering a rectangular window of length L in the column vector w, this window function is provided for completeness; a rectangular window is equivalent to no window at all.

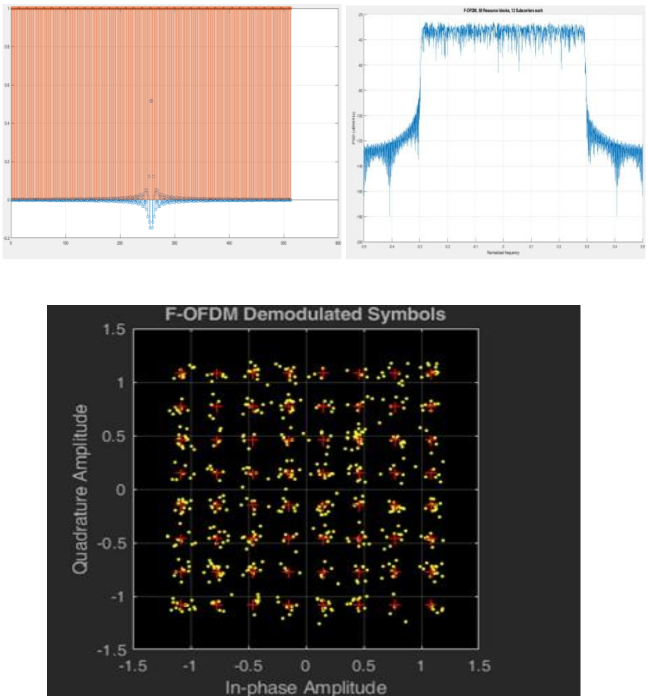

Fig. 3: Window Response, Constellation and PSD of OFDM system with Rectangular window function.

[2] TriangularWindow:

This window function will give M-point triangular window in the column vector, w and triangular window has the coefficients as below,

For M odd:

$$Tri(n) = \begin{cases} \dfrac{2n}{M+1}, 1 \leq n \leq \dfrac{M+1}{2} \\ 2 - \dfrac{2n}{M+1}, \dfrac{M+1}{2} + 1 \leq n \leq M \end{cases}$$

For M Even:

$$Tri(n) = \begin{cases} \dfrac{(2n-1)}{M+1}, 1 \leq n \leq \dfrac{M+1}{2} \\ 2 - \dfrac{(2n-1)}{M+1}, \dfrac{M}{2} + 1 \leq n \leq M \end{cases}$$

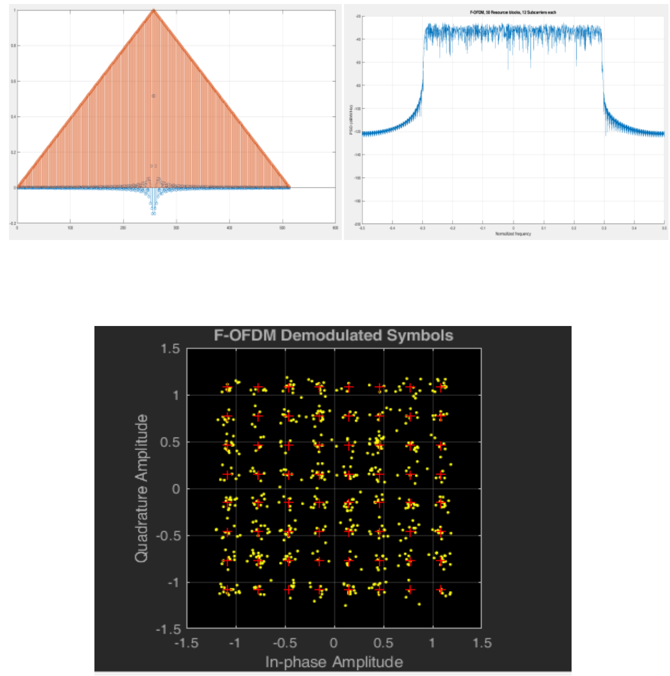

Fig. 4: Window Response, Constellation and PSD of OFDM system with Triangularwindow function.

[3] BartlettWindow:

This window function will give an M-point Bartlett window in the column vector w, where M is equal to positive integer. The coefficients of Bartlett window are as under

$$brtlt(n) = \begin{cases} \dfrac{2n}{M}, 1 \leq n \leq \dfrac{M}{2} \\ 2 - \dfrac{2n}{M}, \dfrac{M}{2} \leq n \leq M \end{cases}$$

The window length N=M+1. There is a huge similarity between Bartlett window and triangular window. Triangle window is nonzero at first and last sample while Bartlett window has zeros at initial and final samples.

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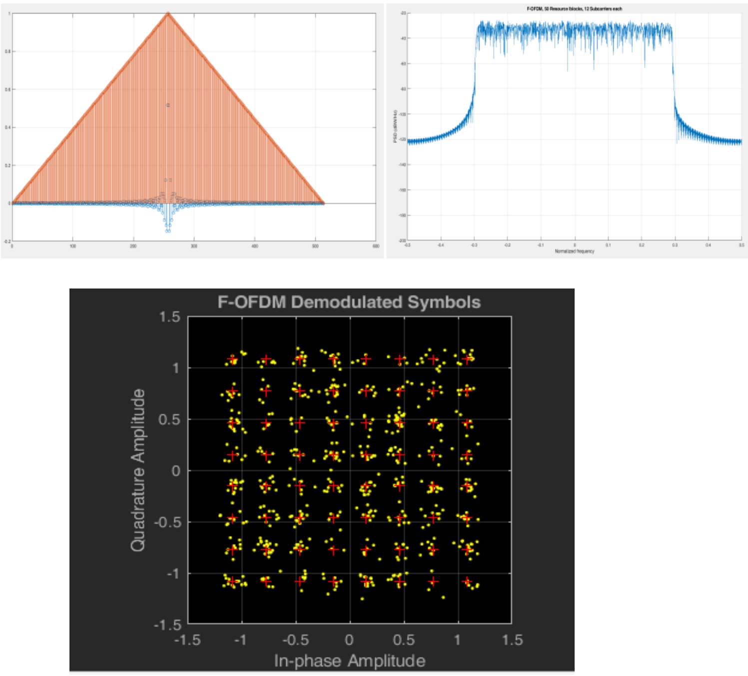


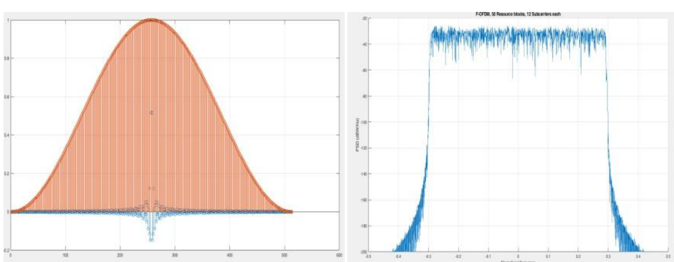
Fig. 5: Window Response, Constellation and PSD of OFDM system with Bartlett window function.

[4] Hanning Window:

The following equation generates the coefficients of a Hann window:

$$hnng(n) = 0.5\left(1 - Cos(2\pi n/m)\right), 0 \leq n \leq M$$

The window length N= M + 1.



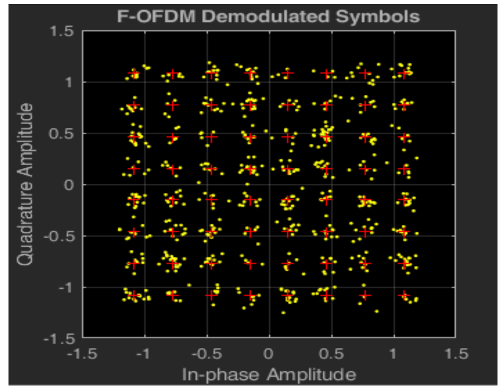


Fig. 6: Window Response, Constellation and PSD of F-OFDM system with Hanning window function.

5. COMPARATIVE ANALYSIS OF WINDOWING FUNCTIONS

Based on the simulation results obtained in section IV for different windowing functions in OFDM, the following comparison can be made amongst the all techniques so as to select the best candidate in OFDM which leads towards the modular realization of communication system.

Window Function	Transition	Pass band Characteristic	OOB Rejection	BER at SNR=18dB
Rectangular	Gradual	Inflate	Very low	$1x10^{-3}$
Triangular	Gradual	Inflate	Low	$8.3x10^{-4}$
Bartlett	Gradual	Flat	Low	$8.3x10^{-4}$
Hanning	Sharp	Flat	Low	$5.5x10^{-4}$

6. CONCLUSION

The main focus of this research work is on OFDM technique and its implementation using multiple windowing aspects so as to analyze the best candidate over the traditional OFDM in 4G LTE system thereby leading towards the upcoming 5G standard. Based on the simulation results, it can be clearly derived that the requirement of flat passband, sharp transition band to minimize guard band and sufficient stop band attenuation will be fulfilled by the OFDM technique with Nutella's Blackman Harris window, Kaiser window and Root Raised Cosine window functions.

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