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The Effect of MIRBBASI-MARTIN Filter on the Performance of Filter Bank Multicarrier Transmultiplexer System

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Abstract

The paper presents a simulation analysis on filter bank multicarrier (FBMC) system with a bank of Mirabbasi-Martin window filter. The Multicarrier modulation system has been introduced as the most suitable technique in the mobile communication system due to its effectiveness in channels with multipath propagation. Cyclic Prefix Orthogonal Frequency division Multiplexing (CP-OFDM) is the dominant multicarrier modulation technique, which achieves high performance in the long term evolution system. However, in some applications such as cognitive radios and the uplink of the multicarrier system where a group of subcarriers is specified to each user, CP-OFDM may be an unfavorable choice. In this paper we focus on proving that FBMC transmultiplexer system provides improved performance with a bank of Mirabbasi-Martin window of filter length is six times greater than the number of the subchannel. The filter length is chosen after simulation results of the overlapping factor effect on the proposed filter. This value of the overlapping factor leads to fast falling off rate of the side lobes and good stopband attenuation with smaller leakage factor. The proposed system can effectively reduce the drawbacks of Cyclic Prefix Orthogonal Frequency Multiplexing. It has been numerically simulated to confirm that the proposed scheme results actually improve the spectrum efficiency, orthogonality and spectrum containment making FBMC a suitable candidate for high speed data transfer using Multicarrier Modulation.

Keywords

MCM, FBMC, CP-OFDM, Overlapping Factor, O-QAM, OOB, EVM

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1. Introduction

Significant growth in mobile data communication requires the development of wireless systems to be able to face the new technologies in efficiently and flexible way. Multicarrier Modulation System (MCM) draws significant attention to improve the performance of multipath propagation and spectral efficiency of the mobile communication system. CP-OFDM is an efficient MCM system but, it has some drawbacks [1-3]. It suffers from poor out of band radiation, producing the interference with neighboring bands, and put strict requirements of orthogonality [4, 5]. Toward this end, it's desirable to propose a technique that reduces OFDM drawbacks. The MCM like Generalized Frequency Division Multiplexing (GFDM), Universal Filtered Multicarrier (UFMC) and Filter Bank Multicarrier (FBMC) are proposed [6, 7]. S. Taheri et al [8] proposed a useful comparison among different multiple carrier techniques like OFDM, FBMC, WCO/COQAM. In order to migiate the negatives of OFDM, FBMC was proposed [9- 15]. The main advantages of FBMC –TMUX is that non-neighboring subchannels are separated by the presence of well-localized filters in

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frequency domain.

PHYDAYS [16] introduce FBMC-TMUX as the system that reduces the shortcomings associated with OFDM.

Mirabbasi-Martin window is a filter function that calculated by a sequence of operations to ensure two basic items. These are a fast falling off rate of side lobes and good stopband performance. If the two items have been achieved, they will give the system better spectral containment and low out of band radiation [17-19]. The focus here is to represent $M/6$ filter bank multicarrier while M is the number of subchannels and 6 represent the value of the overlapping factor (K) and with this, the filter length is 6 times greater than the number of the subchannels.

The rest of this paper is organized as follows. In Sec. 2 FBMC transmultiplexer subsystem is reviewed. The performance of the system including End to End orthogonality, out of band radiation, spectral efficiency, power spectrum density finally, the complexity analysis investigated in Sec. 3. Finally, Sec. 4 the conclusion.

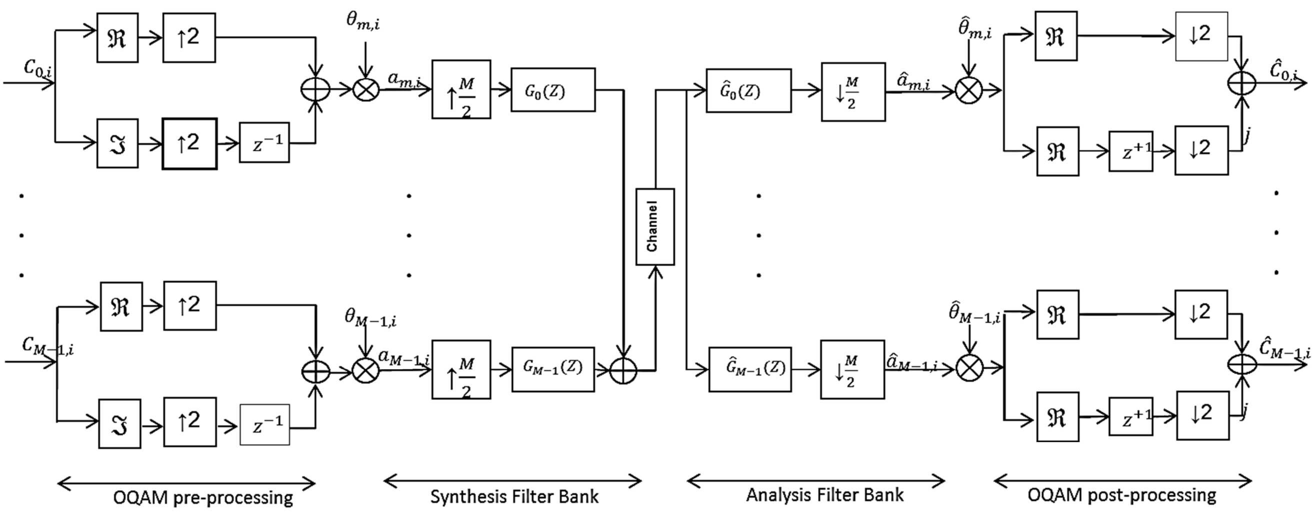


Figure 1. Representation of complex modulated FBMC-TMUX model.

2. FBMC Transmultiplexer System

In this section, FBMC-TMUX system is reviewed. The system is complex modulated FBMC with offset quadrature amplitude modulation Figure 1.

The main parts of the system are the OQAM processing and filtering processing. Combination of OQAM modulation with FBMC leads to the maximum bitrate without the insertion of cyclic prefix [16, 20]. The transmitted signal of the proposed FBMC model can be written as [8].

$$S[k] = \sum_{i=0}^{\infty} \sum_{m=0}^{M} a_{m,i}\, g_m[k - iM/2] \tag{1}$$

Where $m = 0, 1 \ldots M-1$ and $i = 0,1, \ldots I-1$ m, i are the subcarrier index and symbol index respectively.

$$g_m[k] = e^{\frac{j2\pi}{M}mk} g[k] \tag{2}$$

1. $g[k]$ represents Mirabbasi-Martin window equation

2. $e^{\frac{j2\pi}{M}mk}$ Corresponding to a shift in frequency by $\frac{k}{M}$.

The OQAM processing is divided into OQAM pre-processing at the transmitter side and OQAM post-processing at receiving side. The procedure is first to separate QAM symbols imaginary part and real part into new two symbols [20]

$$o_{m,2i} = \begin{cases} \Re(c_{m,i})\ m\ even \\ \Im(c_{m,i})\ m\ odd \end{cases} \tag{3}$$

$$o_{m,2i+1} = \begin{cases} \Im(c_{m,i})\ m\ even \\ \Re(c_{m,i})\ m\ odd \end{cases} \tag{4}$$

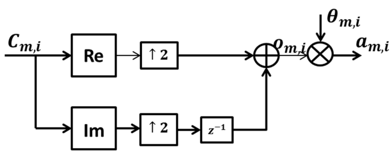
Multiplying by the sequence

$$\theta_{m,i} = e^{j\frac{\pi}{2}(m+i)} = j^{(m+i)} \tag{5}$$

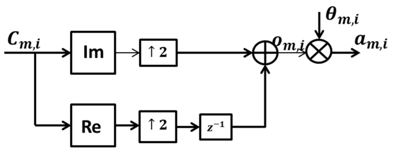
Finally, to complete the O-QAM pre-processing as

$$a_{m,i} = \theta_{m,i}\left(o_{m,i}^{R} + o_{m,i}^{I}\right) \tag{6}$$

Figure 2 represents the procedure of transforming from QAM symbols into OQAM symbols



(a)

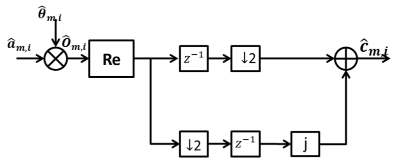


(b)

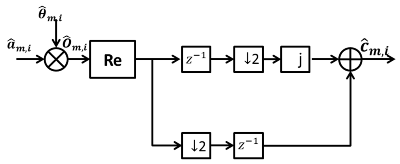
Figure 2. OQAM Pre-Processing (a) m Even (b) m Odd.

While the post-processing Equation (7) and the procedure is demonstrated in figure 3.

$$\hat{c}_{m,i} = \begin{cases} \hat{O}_{m,2i} + j\hat{O}_{m,2i+1} & m\ even \\ \hat{O}_{m,2i+1} + j\hat{O}_{m,2i} & m\ odd \end{cases} \quad (7)$$



(a)



(b)

Figure 3. OQAM Post-Processing (a) m Even (b) m Odd.

The Filtering process is divided to synthesis filter bank at the transmitter side and the analysis filter bank at a receiver side. $\widehat{g_m}[k]$ Analysis filter, $g_m[k]$ synthesis filter bank. They are complex conjugate pair [8].

$$\widehat{g_m}[k] = g_m{}^*[k] \quad (8)$$

The filter window (Mirabbasi-Martin) is the function mathematically represented by Equation (9)

$$g(n) = h_0 + 2\sum_{l=1}^{K-1} h_l \cos\left(\frac{2\pi l n}{N}\right) \quad 0 \le n < N \quad (9)$$

Where K is the overlapping factor and N is the filter length, N =KM. The coefficients (h_l) is calculated by the conditions which achieved excellent frequency selectivity, fast falling rate and high stopband performance [17-19].

K is an integer number, in time domain, represents the number of multicarrier symbol that overlapped. In frequency domain represents the number of coefficient that introduced to FFT inputs. Different values of K are (3, 4, 6 and 8). The filter is simulated by the following flow chart figure 4. The value of k=6 is chosen according to the simulation results which gives the aforementioned positives of the filter in addition to lower leakage factor (the power of side lobes compared to the total window power) figure 5.

The filter frequency coefficients values that inserted between FFT inputs Table 1.

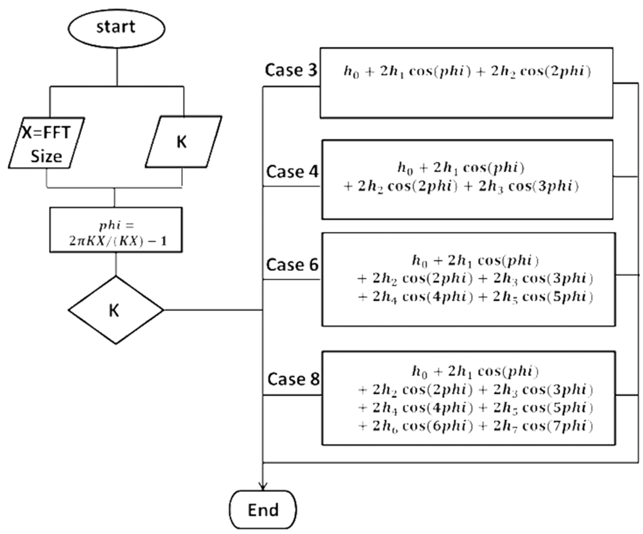


Figure 4. Flow chart for the filter design.

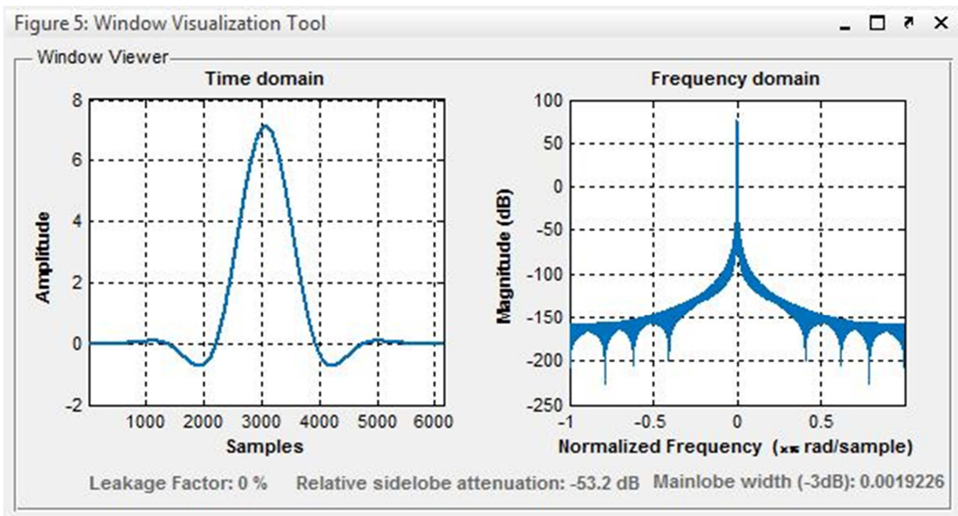


Figure 5. Simulation Results of the filter K=6, FFT=1024.

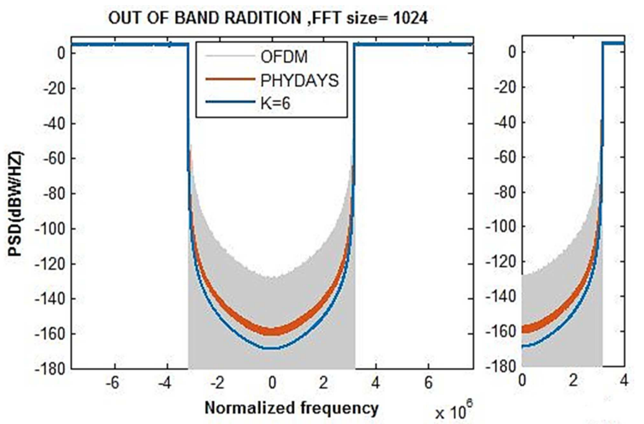


Figure 6. The Effect of Filter on Out of Band Radiation.

Table 1. Filter Coefficient that Inserted between FFT Inputs K=6.

h_0	1
h_1	-0.99818572
h_2	+0.94838678
h_3	-0.70710678
h_4	+0.31711593
h_5	-0.06021021

Numerically simulated relative sidelobes attenuation results of K=6 produces a reduction 13.3db of the PHYDAYS system [16] and 39.9db lower than OFDM. The value of k=6, provides the system better out of band radiation Figure 6.

3. Simulation and Results

In order to implement FBMC with k=6 as shown in figure 7.

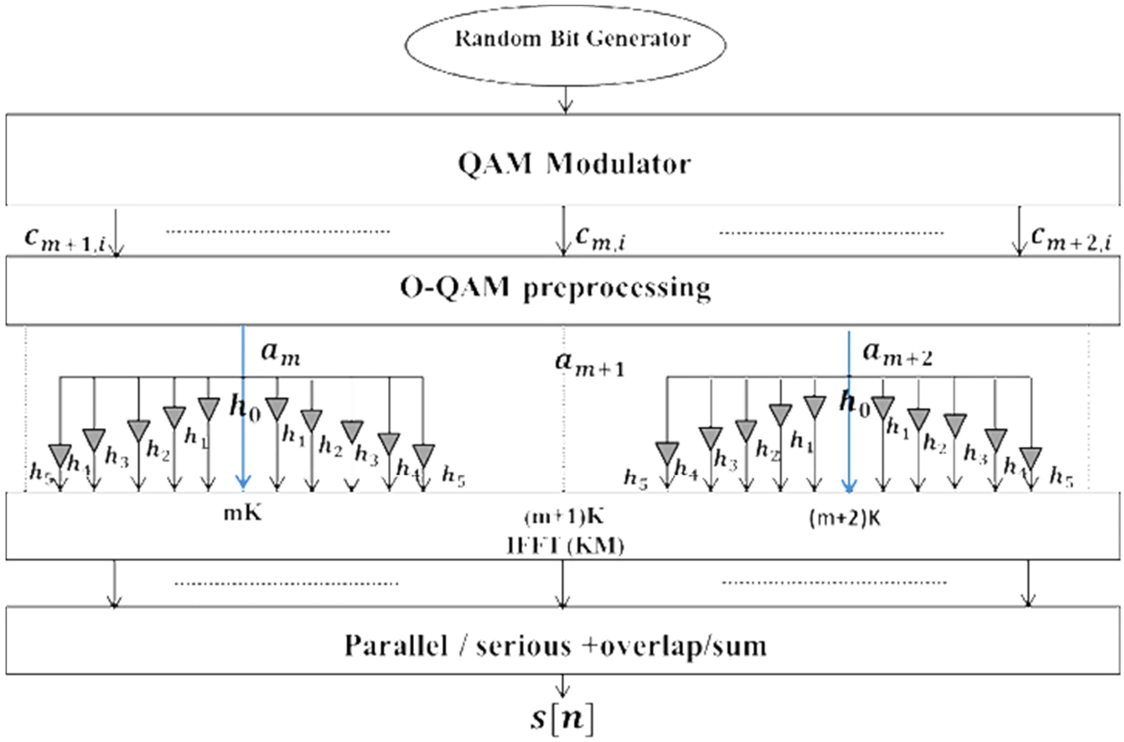


Figure 7. FBMC-TMUX Implementation Procedures "TX".

In time domain, Nyquist theorem for digital transmission stated the fact that: the filter impulse response has to cross the zero axis at the integer multiple of symbol periods [21]. The previous condition is in frequency domain represented by symmetrical coefficients about the cut off frequency.

The two filters groups assumed to be Mirabbasi-Martin filter $g_m[k]$ has overalapping factor of 6. These are synthesis (transmitter) and analysis (receiver), the condition for symmetry is satisfied by squaring the frequency coefficients in Table 1. Once the filter has been designed, the filter bank is obtained by shifts in frequency. These coeffiecients of the filter inserted between IFFT inputs to be added and transmitted as $s[k]$.

The procedure is reversed at the reciever side figure 8, The received data $\hat{s}[k]$ is recovered by the following property of the frequency coefficient of the filter Equation (10) [16].

$$\frac{1}{K}\sum_{l=-K+1}^{K-1}|h_l|^2 = 1 \qquad (10)$$

A great property of the system is that, the subchannel with even index (odd index) don't overlap, this property is employed in the use of offset QAM modulation technique that has been discussed in the previous section.

Table 2 demonstrates the simulation parameters as in [12].

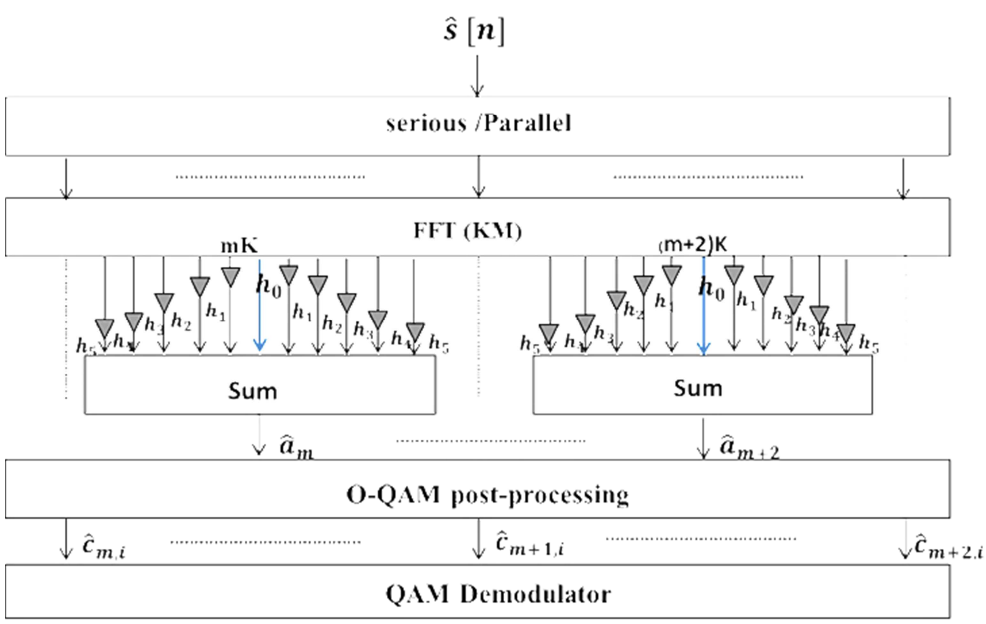


Figure 8. FBMC-TMUX Implementation Procedures "RX".

Table 2. Simulation parameters.

Parameters	Modulation	K	FFT Size	FS
Value	64-QAM	6	1024	15360000

MCM system quality can be measured by end to end orthogonality analysis. Error Vector Magnitude in equation (11) mathematically represents the measure of end to end orthogonality [8]

$$EVM_i\ (dB) = 10\log_{10}\left(\frac{\Sigma_m |a_{m,i} - \hat{a}_{m,i}|^2}{\Sigma_m |a_{m,i}|^2}\right) \qquad (11)$$

Where $a_{m,i}$ OQAM symbol which modulating the subcarrier at the transmitter, while $\hat{a}_{m,i}$ at a receiver side.

The proposed system gives better orthogonality between transmitted and received QAM symbols than that of OFDM system as depicted in figure 9.

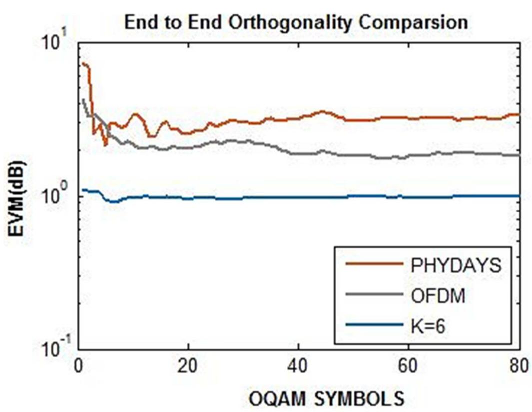


Figure 9. End to End Orthogonality Comparison.

Figure 10 represent a comparison of power spectral density (PSD) of FBMC (K=6), PHYDAY system and OFDM. The figure demonstrates an important advantage of FBMC system with K=6, the system has better spectrum containment. Accordingly to this property FBMC-TMUX enhances its performance in the cognitive radio network technique.

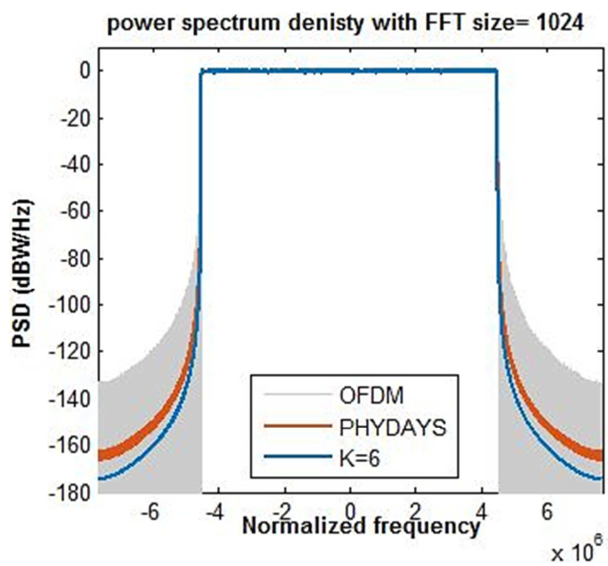


Figure 10. Power Spectrum Density Comparison.

Another advantage of the FBMC system is cyclic prefix removal. The general form that may describe the bandwidth efficiency is written as equation (12)

$$\epsilon = \delta(\square)\alpha\beta \qquad (12)$$

Where $\delta(\square)$ lattice density and equal to 1 for the two systems [19], α reduction factor caused by the insertion of the cyclic prefix and β the effect of tails of the modulated block of symbols [8] and their values in the following Table 3.

Table 3. Spectral Efficiency Parameters.

SYSTEM	α	β
CP-OFDM	$\frac{M}{M+L_{CP}}$	1
FBMC	1	$\frac{p}{p+K-.5}$

Where M is FFT size, L_{CP} is the cyclic prefix length ($\frac{1}{4}$ or $\frac{1}{10}$) M, p is the number of modulated symbols per frame and K is the overlapping factor.

The spectral efficiency related to number of subchannel used presented in figure 11.

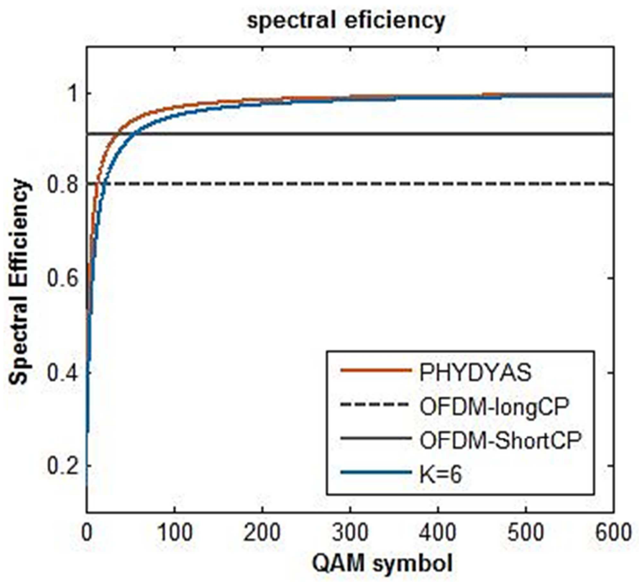


Figure 11. Spectral Efficiency Comparisons.

The proposed system will give better efficiency with increasing number of sub-channels as depicted in figure 12.

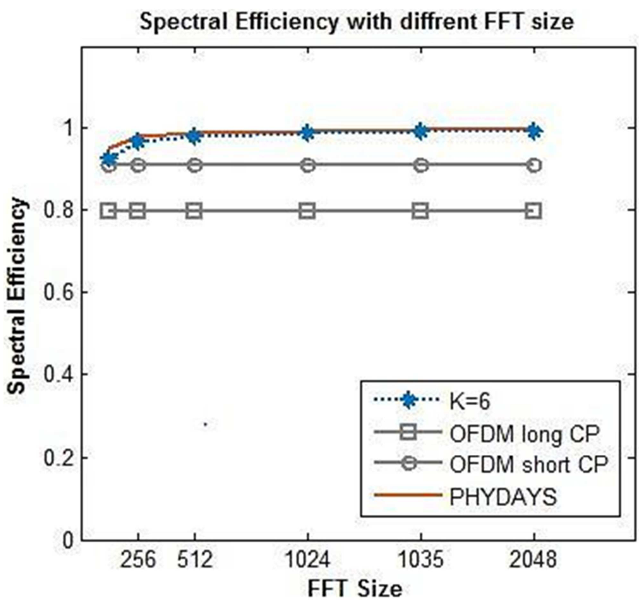


Figure 12. Spectral Efficiency with different FFT size.

The most significant drawback accompanying with FBMC system is the complexity analysis, the measure of complexity analysis is the floating point operation (FLOPS). The floating point operation definition differs from one processor to another. The focus here is on the number of real multiplications. The most efficient FFT algorithm parameter is split-radix [22] and it will be expressed by equation (13) [8].

$$C_{FFT} = M(log_2M - 3) + 4 \quad (13)$$

At transmitter, with OFDM C_{OFDM}=C_{FFT}. In case of FBMC the complexity of complex (real and imaginary) symbol modulation

$$C_{FBMC} = 2(C_{FFT} + 2KM) \quad (14)$$

According to equation (14) FBMC presented higher complexity than OFDM, this drawback can be tolerated because of the positives of improved performance can be a preferable engineering tradeoff.

4. Conclusion

Filter bank multicarrier transmultiplexer system with a bank of Mirabbasi-Martin filters of overlapping factor K=6 has been proposed and numerically simulated. Exploiting offset quadrature amplitude modulation with the value of k will give higher orthogonality. Significant improvement gained in terms of spectrum containment moreover, lower out of band radiation with an enhancement to the reduction of intercarrier interference. The scheme proposed gives higher spectrum efficiency with increasing the number of subchannels. Complexity analysis gives us the fact the system is more complex than CP-OFDM. By the end the proposed scheme is a strong competitive processing waveform for 5G.

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