Analysis of OFDM and filter bank multicarrier with offset quadrature amplitude modulation for 5G communication: a comparative study

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Article Info

Article history:

Received Apr 10, 2026
Revised Jun 15, 2026
Accepted Jun 27, 2026

Keywords:

5G communications
Channel estimation
FBMC/OQAM
OFDM
PAPR
PSD
Spectral efficiency

ABSTRACT

Emerging applications for 5G and beyond require wireless communication systems with high spectral efficiency, low latency, reliable synchronization, and robust channel estimation techniques. This paper presents a comparative analysis between orthogonal frequency division multiplexing (OFDM) and filter bank multicarrier with offset quadrature amplitude modulation (FBMC/OQAM) under identical simulation conditions. The comparison is performed in terms of spectral efficiency, power spectral density (PSD), bit error rate (BER), peak-to-average power ratio (PAPR), and channel estimation performance. Simulation results show that FBMC/OQAM has higher spectral efficiency and significantly reduced out-of-band (OOB) emissions than OFDM due to its superior spectral containment. Moreover, FBMC/OQAM provides better channel estimation performance in the frequency-selective multipath fading environment. On the other hand, OFDM has lower computational complexity and better PAPR performance. The obtained results highlight the performance differences between OFDM and FBMC/OQAM systems and demonstrate the potential of FBMC/OQAM as a promising waveform candidate for future wireless communication systems.

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1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is widely used in modern wireless communication systems due to its robustness to multipath fading, high data rate, and spectrum efficiency [1]-[4]. However, OFDM suffers from some limitations such as high out-of-band (OOB) emissions, cyclic prefix (CP) overhead, and tight synchronization requirements, which lower the spectral efficiency and impair the system performance in highly dynamic wireless environments.

The filter bank multicarrier with offset quadrature amplitude modulation (FBMC/OQAM) has been proposed as a promising alternative waveform for future wireless communication systems such as 5G and beyond to overcome these limitations [2], [5], [6]. Unlike OFDM, FBMC/OQAM uses pulse shaping filters instead of rectangular windowing filters and does not require CP insertion. Hence, FBMC/OQAM provides better spectral containment, lower sidelobe levels, and higher spectral efficiency [7]-[10]. In addition to spectral efficiency, channel estimation is still an important issue for both OFDM and FBMC/OQAM systems, especially in frequency-selective fading channels. Accurate channel estimation significantly affects system reliability, bit error rate (BER) performance, and interference mitigation capability. Thus, efficient channel estimation techniques are required to improve the performance of multicarrier communication systems under practical wireless channel conditions [11].

2. RELATED WORKS

Nissel *et al.* [12] compared OFDM with FBMC/OQAM and showed that FBMC/OQAM has improved spectral efficiency and flexible resource allocation. However, the study mainly focused on spectral characteristics without much investigation of channel estimation performance under various wireless channel conditions. The work presented investigated the magnitude response of FBMC and OFDM systems for different overlapping factors [13]. The results obtained showed that FBMC achieves better sidelobe attenuation and reduced ISI and ICI. Nevertheless, the study did not include a comprehensive analysis of BER and channel estimation performance.

Abdel-Atty *et al.* [14] evaluated different prototype pulse-shaping filters to improve the performance of FBMC/OQAM systems. The simulation results indicated that FBMC/OQAM achieves spectral characteristics superior to OFDM while maintaining comparable BER performance. However, computational complexity and channel estimation trade-offs were not sufficiently discussed. Moreover, several works have studied various channel estimation techniques for FBMC/OQAM systems. The reseearchers [15], [16] have studied several interference approximation method (IAM) techniques to improve the FBMC/OQAM system performance regarding channel estimation, such as IAM-R, IAM-C, E-IAM-C, and N-IAM. They showed that the IAM-based methods can significantly improve the channel estimation accuracy and BER performance. However, a comprehensive comparative study between OFDM and FBMC/OQAM in terms of power spectral density (PSD), BER, peak-to-average power ratio (PAPR), and channel estimation techniques under equivalent channel conditions remains limited.

Although several studies have investigated OFDM and FBMC/OQAM systems, most existing works have focused on individual performance metrics such as spectral efficiency, BER, and channel estimation separately. In addition, limited studies have provided a comprehensive comparison of PSD, BER, PAPR, and multiple channel estimation techniques under identical simulation conditions. Therefore, a unified evaluation framework is still required to provide a deeper understanding of the performance characteristics and design considerations of OFDM and FBMC/OQAM systems for future wireless communication networks.

To fill this gap, this paper presents a unified comparative framework of OFDM and FBMC/OQAM systems under the same simulation conditions. The proposed framework jointly evaluates spectral efficiency, PSD, BER, PAPR, and several channel estimation techniques including least squares estimation (LSE), Minimum mean square error (MMSE), Improved domain transform estimation (IDTE), and IAM-based approaches. The presented analysis provides a comprehensive understanding of spectral containment, computational complexity, synchronization requirements, and channel estimation performance, thereby helping in waveform selection for future 5G and beyond wireless communication systems.

The main contributions of this paper are summarized as follows:

- A unified comparative analysis between OFDM and FBMC/OQAM systems is presented under identical simulation conditions.
- The performance of both systems is analyzed based on PSD, BER, PAPR, and spectral efficiency.
- A comparative study of various channel estimation techniques such as LSE, MMSE, IDTE, and IAM-based methods is provided.
- The performance differences regarding spectral containment, channel estimation accuracy, computational complexity, and PAPR performance are investigated for future wireless communication systems.

The remainder of this paper is organized as follows. Section 2 presents the system models of OFDM and FBMC/OQAM. Section 3 discusses the adopted channel estimation techniques. Section 4 presents simulation results and performance analysis. Section 5 presents the conclusion and future research directions.

3. METHOD

This section presents the system models of OFDM and FBMC/OQAM systems. The block diagrams and the mathematical expressions of both systems are presented to highlight their main structural differences. The pros and cons of both systems are also discussed in terms of spectral efficiency, interference mitigation, and computational complexity [17], [18].

3.1. Orthogonal frequency division multiplexing

Figure 1 illustrates that the input data symbols are first modulated using QAM and then converted into parallel subcarriers using the inverse fast fourier transform (IFFT). A CP is added to overcome inter-symbol interference (ISI) caused by multipath fading channels. The OFDM signal is transmitted through the wireless channel. At the receiver, the CP is removed, and a fast fourier transform (FFT) operation is performed to recover the transmitted data symbols.

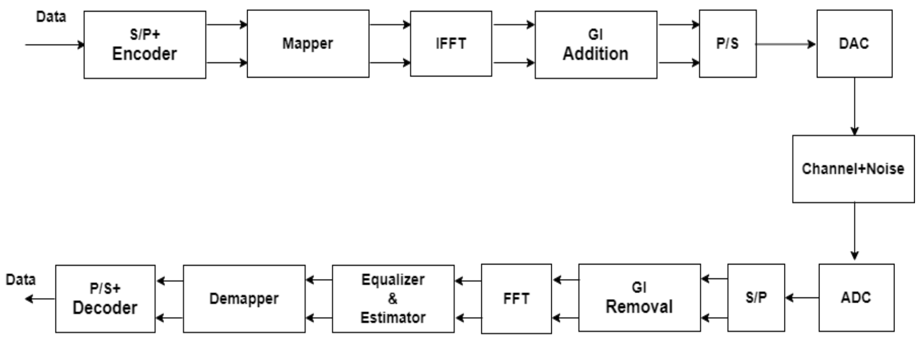

Figure 1. OFDM system model

The mathematical representation of the OFDM signal is as:

$$x(t) = \sum_{m=0}^{M-1} x_m(n + m(N + N_{cp})) \quad (1)$$

where,

$$x_m(n) = (\frac{1}{\sqrt{N}}) \sum_{k=0}^{N-1} x_{m,k} e^{\frac{j2\pi kn}{N}} \quad (2)$$

$(x_{m,k})$ represents the transmitted data symbols, (N) denotes the number of subcarriers, (M) is the number of OFDM symbols, (N_{cp}) represents the CP length, and (n) is the discrete-time sample index.

$$y_n = h_n * x_n + w_n \quad (3)$$

$$y_n = \sum_{k=0}^{L-1} h_k \, x_{n-k} + w_n \quad (4)$$

Where y_n denotes the received signal, (h_k) represents the channel impulse response (CIR), (L) is its length and (w_n) represents the additive noise component in the time domain.

3.2. Filter bank multicarrier/offset quadrature amplitude modulation

The main difference between FBMC/OQAM and OFDM is the type of filtering used in the two systems. OFDM uses a rectangular windowing filter, whereas FBMC/OQAM uses pulse-shaping filters to reduce OOB emissions and improve spectral localization. In addition, FBMC/OQAM does not need to insert a CP, which improves spectral efficiency [19]-[21]. The block diagram of the FBMC/OQAM transceiver system is depicted in Figure 2. Analysis filter bank (AFB) and synthesis filter bank (SFB) are two core blocks of FBMC/OQAM systems, which decompose and synthesize the transmitted signal into subcarriers and thus make efficient data transmission possible. The output of an FBMC/OQAM SFB can be written as:

$$s(l) = \sum_{m=0}^{M-1} \sum_n d_{m,n} g_{m,n}(l) \quad (5)$$

where (g) represents the prototype filter impulse response with length (L_g) and $L_g = KM$, (K) denotes the overlapping factor; (M) is the number of subcarriers, $(\varphi_{m,n})$ represents the additional phase shift associated with subcarrier index m and symbol index n, which is $\varphi_{m,n} = (m+n)\frac{\pi}{2} + \emptyset_0$ and $\emptyset_0 = mn\pi$ [15], [22].

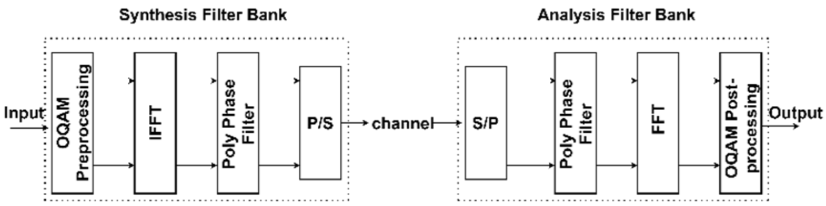

Figure 2. FBMC/OQAM transceiver model

The associated subcarrier functions $g_{m,n}(l)$ are only orthogonal over the real field because of the way the pulse g is designed and constructed [23]. It implies that there will be some interference that is entirely imaginary at AFB output. The imaginary intrinsic interference width is provided by:

$$\sum g_{m,n}(l)\, {g^*}_{p,q}(l) = j < g >_{m,n}^{p,q} \quad (6)$$

where (p) represents the subcarrier index, (q) denotes the OQAM symbol time index and $< g >_{m,n}^{p,q}$ the intrinsic interference term between neighboring frequency-time points. The channel's output with impulse response (h) with length (L_h):

$$y(l) = \sum_{k=0}^{L_h-1} h(k) s(l-k) + w(l) \quad (7)$$

where $(w(l))$ represents the additive white gaussian noise (AWGN) component with zero mean and variance (σ^2). The output of AFB at the p, q frequency-time FT point.

$$y_{p,q} = \sum_l y(l) g_{p,q}^*(l) \quad (8)$$

$$y_{p,q} = \sum_{k=0}^{L_h-1} h(k) \sum_l s(l-k)\, g_{p,q}^*(l)\ \sum_l w(l)\, g_{p,q}^*(l) \quad (9)$$

$$y_{p,q} = \sum_{k=0}^{L_h-1} h(k) \sum_l \sum_{m=0}^{M-1} \sum_n d_{m,n} g\left(l-k-n\frac{M}{2}\right) g\left(l-q\frac{M}{2}\right) \times\ e^{j\frac{2\pi}{M}(m-p)\left(l-\frac{L_g-1}{2}\right)} e^{-j\frac{2\pi}{M}mk} e^{j(\varphi_{m,n}-\varphi_{p,q})} + \eta_{p,q} \quad (10)$$

The AFB output samples in terms of the CIR:

$$y_{p,q} = H_{p,q} d_{p,q} + I_{p,q} + \eta_{p,q} \quad (11)$$

where $(H_{p,q})$ represents the channel frequency response at the corresponding frequency-time point, and $(I_{p,q})$ represents the intrinsic interference component, and $(\eta_{p,q})$ denotes the gaussian noise term with zero mean and variance (σ^2).

$$I_{p,q} = j\ \sum_{m=0}^{M-1} \sum_n H_{m,n} d_{m,n} < g >_{m,n}^{p,q} + \eta_{p,q} \quad (12)$$

$$y_{p,q} = H_{p,q}[d_{p,q} + j\ \sum_{m=0}^{M-1} \sum_n H_{m,n} d_{m,n} < g >_{m,n}^{p,q}] + \eta_{p,q} \quad (13)$$

Owing to the well-localized pulses g in both time and frequency, interference from FT points outside of a neighborhood of $\Omega_{p,q}$ (p, q) is minimal and negligible.

$$y_{p,q} \approx H_{p,q} c_{p,q} + \eta_{p,q} \quad (14)$$

Were,

$$c_{p,q} = d_{p,q} + j\ \sum_{(m,n)\in\Omega_{p,q}} d_{m,n} < g >_{m,n}^{p,q} \quad (15)$$

$$\hat{H}_{p,q} = \frac{y_{p,q}}{c_{p,q}} =\ H_{p,q} + \frac{\eta_{p,q}}{c_{p,q}} \quad (16)$$

When known training sequences are transmitted at the corresponding frequency-time points and their neighboring positions, the pseudo-pilot symbols can be utilized to estimate the channel frequency response. Therefore, preamble-based channel estimation techniques are commonly adopted in FBMC/OQAM systems to improve channel estimation accuracy [21]-[33]. Table 1 illustrates the main differences between OFDM and FBMC/OQAM techniques.

Table 1. Comparison between OFDM and FBMC/OQAM

Property	OFDM	FBMC/OQAM
CP	Required	Not required
Filter	Rectangular windowing filter	Pulse shaping filter
Side lobes	Large	Low
MIMO systems	High compatibility	Low compatibility
Equalizer	Single tap	Multiple tap
Synchronization	Requires high synchronization	Requires less synchronization
Computational complexity	Very low	High
PAPR	High	High

3.3. Channel estimation techniques for OFDM and FBMC/OQAM

In this section, we present examples of the channel estimation techniques used in OFDM and FBMC/OQAM systems. For OFDM systems, we review the classic channel estimation methods such as LSE, MMSE, and IDTE. For FBMC/OQAM systems, channel estimation is more complicated due to the overlapping of subcarriers and the inherent interference among adjacent frequency-time points. As a result, IAM-based methods are adopted to alleviate the interference and improve the precision of channel estimation.

3.3.1. Least squares estimation

The LS estimators are calculated with relatively low complexity, lacking any understanding of the channel statistics; however, they suffer from a high mean-square error. Typically, the LS method is employed to obtain initial channel estimates at the pilot sub-carriers, which are subsequently enhanced through various methods [21].

$$\hat{H}_{LS} = X^{-1}.Y = \left[\frac{Y_0}{X_0}.\frac{Y_1}{X_1} \dots\dots\dots\dots.\frac{Y_{N_p-1}}{X_{N_p-1}}\right]^T \quad (17)$$

3.3.2. Minimum mean square error

The MMSE channel estimation method takes advantage of the statistical nature of the wireless channel and noise to obtain a higher estimation accuracy than LSE. But the computational complexity of MMSE increases greatly with the number of subcarriers because of the matrix inversion operations. Therefore, MMSE can achieve a better performance in estimation at the cost of higher computational complexity [34], [35]. The error of channel estimation e:

$$e = H - \hat{H} \quad (18)$$

where (H) is the actual estimation and $(\hat{H})$ is the raw channel estimation, and the MSE of the channel is:

$$E\{|e|^2\} = E\left\{\left|H - \hat{H}\right|^2\right\} \quad (19)$$

where $(E\{\ \})$ is the expectation since the channel and AWGN are not correlated.

$$\hat{H}_{MMSE} = R_{HY}R_{YY}^{-1}Y \quad (20)$$

where $(\hat{H}_{MMSE})$ is the estimation of CFR at a pilot position of the channel, (R_{HH}) and (R_{YY}) are auto-covariance matrices of the channel and received signal, respectively, and (R_{HY}) is the cross-covariance matrix between the channel response and the received signal.

3.3.3. Improved domain transform estimation method

The IDTE method reduces computational complexity by avoiding matrix inversion operations while maintaining acceptable channel estimation performance. The method estimates the time-domain CIR using pilot subcarriers and transform-domain processing techniques [26].

$$\hat{h}_l = \frac{1}{k_p} I_l F_{K_P,l}^H . D\left(X_{k_p}\right)^H . Y_{k_p} \quad (21)$$

Where $(\hat{h}_l)$ represents the estimated CIR, (X_{k_p}) denotes the transmitted pilot subcarriers, (Y_{k_p}) represents the received pilot subcarriers, $(D\left(X_{k_p}\right))$ is a diagonal matrix with (X_{k_p}) on its diagonal, $(.)^H$ denotes Hermitian transpose, $(F_{K_p,l})$ is the FFT matrix of size $(K_p \text{ x } l)$, I_l is the identity matrix of size $(l \text{ x } l)$ and l is the length of the channel. Based on (21), the estimation matrix size $(\hat{h}_l)$ solely relies on the channel's length and is independent of the pilot subcarrier count or OFDM symbol size. We avoided using an inverse matrix in the LSE and MMSE.

Channel estimation in FBMC/OQAM systems is more challenging than in OFDM systems due to intrinsic interference and the absence of complex-domain orthogonality [36], [37]. Therefore, several preamble-based and frequency-domain estimation techniques have been proposed to improve estimation accuracy while maintaining low computational complexity.

For the aim of channel estimation, known (training) sequences can be placed at isolated FT points at the beginning of a frame and/or throughout a frame. The two main pilot configurations are preamble and scattered pilots. Preamble-based channel estimation starts each transmission frame with a pilot preamble to enable channel estimation. For channel stability in time and frequency [27], [29], several current channel estimation techniques in FBMC/OQAM systems are based on IAM techniques.

3.3.4. Interference approximation method

IAM is one of the most widely used preamble-based channel estimation techniques for FBMC/OQAM systems, particularly in highly frequency-selective fading channels. The IAM approach approximates the intrinsic imaginary interference using predefined pilot structures and interference weights derived from the employed prototype filter. Several interference mitigation approaches for FBMC/OQAM systems were also investigated in [38]. Based on the selected prototype filter, the interference coefficients can be calculated as illustrated in Figure 3 and Table 2.

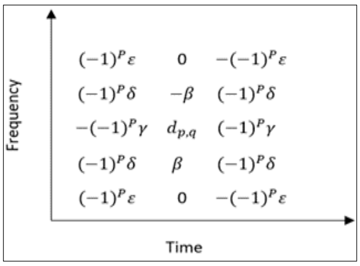

Figure 3. Interference weights pattern

Table 2. Interference weights pattern

Interference weights pattern quantities
$\beta = e^{-j\frac{2\pi}{M}\frac{l_g-1}{2}} \sum_{l=0}^{l_g-1} g^2(l)\, e^{j\frac{2\pi}{M}l}$
$\gamma = \sum_{l=\frac{M}{2}}^{l_g-1} g(l) g\left(l-\frac{M}{2}\right)$
$\delta = -j\, e^{-j\frac{2\pi}{M}\frac{l_g-1}{2}} \sum_{l=\frac{M}{2}}^{l_g-1} g(l) g\left(l-\frac{M}{2}\right) e^{j\frac{2\pi}{M}}$
$\varepsilon = e^{\mp j\frac{2\pi}{M}(l_g-1)} \sum_{l=\frac{M}{2}}^{l_g-1} g(l) g\left(l-\frac{M}{2}\right) e^{\pm j2\frac{2\pi}{M}}$

Several IAM-based preamble schemes have been proposed for FBMC/OQAM systems, including IAM-R, IAM-C, E-IAM-C, NPS, and N-IAM [30], [39], [40]. These schemes mainly differ in pilot arrangement and pseudo-pilot generation strategies. Among these techniques, E-IAM-C and N-IAM generally provide higher pseudo-pilot magnitudes and improved channel estimation performance compared with conventional IAM schemes. Table 3 summarizes the main differences between the considered IAM techniques [24], [25], [29].

The selected channel estimation techniques represent different trade-offs between estimation accuracy and computational complexity. LSE provides low computational complexity but suffers from performance degradation in noisy environments. The MMSE offers better estimation accuracy exploiting the channel statistics but at the expense of a higher complexity, since it involves matrix inversion operations. The IDTE reduces the computational load by working in the transform domain, while still providing a satisfactory estimation performance. For FBMC/OQAM systems, IAM-based approaches are particularly interesting, since they can mitigate the inherent interference and improve the channel estimation accuracy in highly frequency-selective fading channels. For these reasons, we chose these techniques to enable a detailed comparison between low-complexity and high-performance estimation techniques.

Table 3. Comparison between IAM schemes

	IAM-R	IAM-C	E-IAM-C	NPS	N-IAM
Preamble schemes	$\begin{bmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 1 & 0 \\ 0 & -j & 0 \\ 0 & -1 & 0 \\ 0 & j & 0 \\ 0 & 1 & 0 \\ 0 & -j & 0 \\ 0 & -1 & 0 \\ 0 & j & 0 \end{bmatrix}$	$\begin{bmatrix} j & 1 & -j \\ -1 & -j & 1 \\ -j & -1 & j \\ 1 & j & -1 \\ j & 1 & -j \\ -1 & -j & 1 \\ -j & -1 & j \\ 1 & j & -1 \end{bmatrix}$	$\begin{bmatrix} 1 & -1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & -1 \\ 1 & -1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & -1 \\ 1 & -1 & 1 \end{bmatrix}$	$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & -1 & 0 \\ -1 & 1 & 1 \\ 0 & 1 & 0 \\ 0 & -1 & 0 \end{bmatrix}$
Pseudo pilot magnitude (odd-indexed subcarriers)	$d\sqrt{1+4\beta^2}$	$d\|1+2\beta\|$	$d\|1+2(\beta+\gamma)\|$	$d\sqrt{1+4(\beta+\delta)^2}$	$d\sqrt{1+4(\beta+\gamma)^2}$
Pseudo pilot magnitude (even-indexed subcarriers)	$d\sqrt{1+4\beta^2}$	$d\|1+2\beta\|$	$d\|1+2(\beta+\gamma)\|$	$d\sqrt{1+4(\beta-\gamma)^2}$	$d\sqrt{1+4\beta^2}$

4. RESULTS AND DISCUSSION

This section presents the simulation results obtained for OFDM and FBMC/OQAM systems. The performance comparison is conducted in terms of PSD, BER, PAPR, filter response, and channel estimation performance. Table 4 summarizes the main simulation parameters used throughout the analysis. To ensure a fair comparative evaluation, both OFDM and FBMC/OQAM systems were simulated under identical transmission parameters and frequency-selective multipath fading channel conditions. The performance of both systems was evaluated under different channel conditions using the simulation parameters summarized in Table 4. The results obtained emphasize the design considerations between spectral efficiency, interference mitigation, computational complexity, and signal quality for both systems.

Table 4. Simulation parameters used for OFDM and FBMC/OQAM systems

Parameters	OFDM	FBMC
Modulation	QAM	OQAM
FFT size	1024	1024
Number of symbols	100	100
CP	128	N/A
Overlapping Factor	N/A	K=4
SNR range	0-20 dB	0-20 dB
Channel model	Rayleigh	Rayleigh

Figure 4 demonstrates the PSD performance of OFDM and FBMC/OQAM systems. FBMC/OQAM has much lower sidelobe levels and improved spectral localization than OFDM. For instance, the sidelobe level of FBMC/OQAM is about -154 dB at the middle point, while the sidelobe level of OFDM is about -28.6 dB for the same simulation conditions. This is mainly due to the pulse-shaping filters in FBMC/OQAM systems, which have better frequency localization than the rectangular windowing filter in OFDM. Thus, FBMC/OQAM has better spectral containment and higher spectral efficiency [5], [6], [21], [41]. These results are consistent with the findings reported in [13] and [14], where FBMC/OQAM systems showed lower sidelobe leakage and better spectral localization than conventional OFDM systems.

Figure 5 illustrates the frequency response of the prototype filters used in OFDM and FBMC/OQAM systems. The FBMC/OQAM filter demonstrates faster sidelobe attenuation and lower spectral leakage compared to the OFDM rectangular filter. Therefore, FBMC/OQAM systems experience lower adjacent channel interference and improved spectral localization [28], [31], [42].

Figure 6 shows the frequency response of FBMC/OQAM systems for different overlapping factors (K = 2, 3, and 4). The frequency response decays rapidly over the sidebands. As the overlapping factor increases, the frequency localization is improved and the separation between adjacent subchannels becomes better, which reduces the interference and the signal distortion. However, increasing the overlapping factor also increases computational complexity and filter length, which introduces additional processing overhead in FBMC/OQAM systems [43]-[45].

Figure 7 shows the impulse responses of the rectangular prototype filter used in OFDM and the PHYDIAS filter used in FBMC/OQAM systems. The rectangular filter has sharp transitions and relatively high sidelobe levels. The PHYDIAS filter has a smoother response with lower sidelobe leakage. As a result, the PHYDIAS filter reduces spectral leakage and minimizes ISI and inter-carrier interference (ICI) more effectively than the rectangular filter employed in OFDM systems.

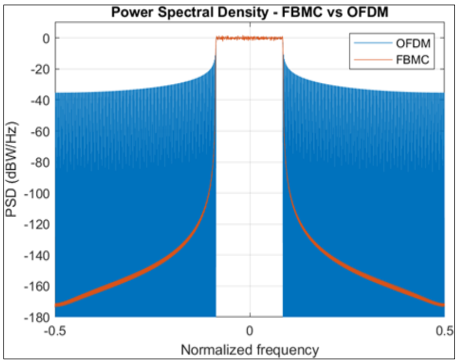

Figure 4. PSD comparison showing lower sidelobe leakage and improved spectral containment for FBMC/OQAM compared with OFDM

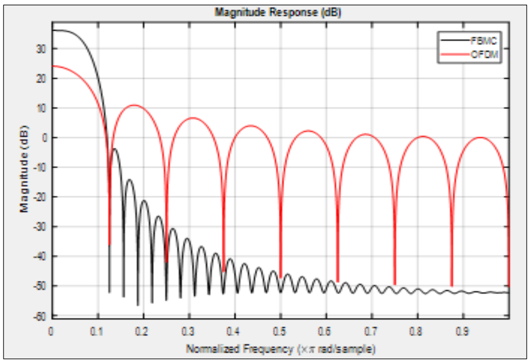

Figure 5. Frequency response comparison between OFDM and FBMC/OQAM prototype filters

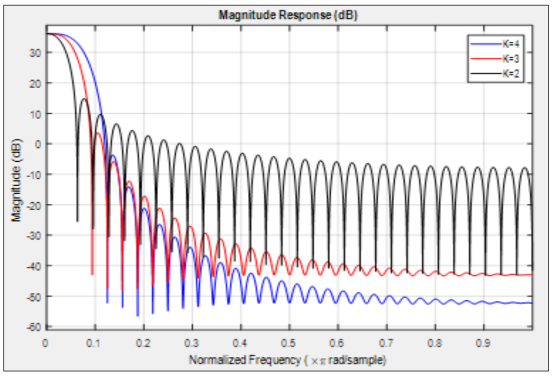

Figure 6. Prototype filter of FBMC with different K

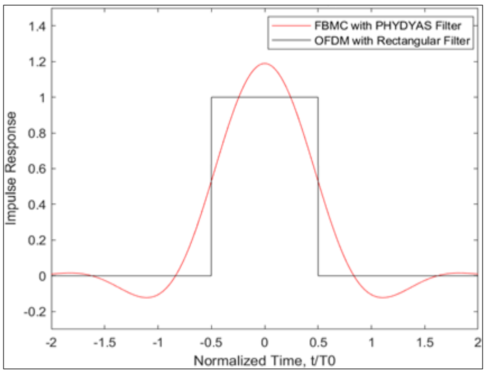

Figure 7. Impulse response of prototype filter of OFDM and FBMC

Figure 8 compares the BER performance of OFDM and FBMC/OQAM systems. The results indicate that the BER performance of the two systems is similar under certain channel conditions which is consistent with the findings reported in [24]. However, FBMC/OQAM provides improved spectral characteristics and lower OOB emissions compared with OFDM. The obtained BER results are also in line with the works in [24], [39] where it was mentioned that FBMC/OQAM systems can achieve similar BER performance as OFDM systems under proper channel estimation and synchronization conditions.

Figure 9 presents the performance comparison of different channel estimation techniques for OFDM and FBMC/OQAM systems. Moreover, FBMC/OQAM with E-IAM-C estimation exhibits lower estimation error than conventional OFDM channel estimation techniques, especially at low SNR values.

A common approach is to estimate the probability that the PAPR is above a threshold using the complementary cumulative distribution function (CCDF). Figure 10 shows the PAPR performance of OFDM and FBMC/OQAM signals. The results show that FBMC/OQAM has higher PAPR values due to the filtering operations and overlapping structure used in the system. Figure 11 shows the CCDF performance of OFDM and FBMC/OQAM systems without applying PAPR reduction techniques. At a CCDF value of 0.1, OFDM achieves approximately 3 dB lower PAPR than FBMC/OQAM. Therefore, although FBMC/OQAM provides improved spectral efficiency and spectral containment, OFDM maintains better PAPR performance under the considered simulation conditions [13]. These observations are also consistent with previous studies reported in [13], [44] which reported similar PAPR behavior for FBMC/OQAM systems under comparable transmission conditions [46].

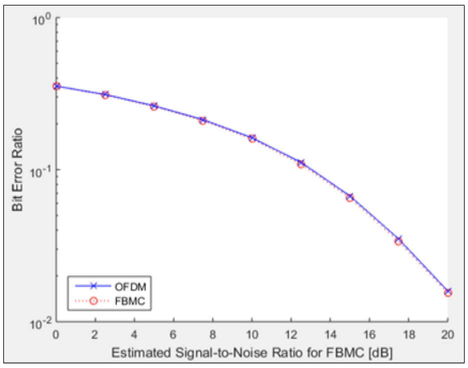

Figure 8. BER performance comparison between OFDM and FBMC/OQAM systems under frequency-selective fading conditions

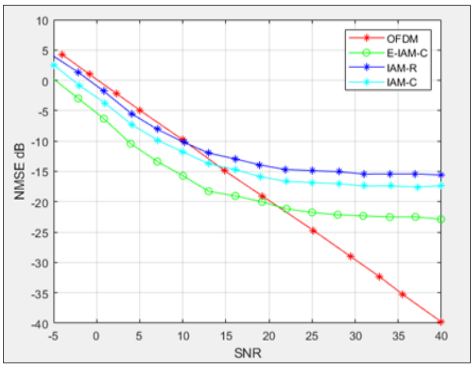

Figure 9. Channel estimation performance comparison for OFDM and FBMC/OQAM systems

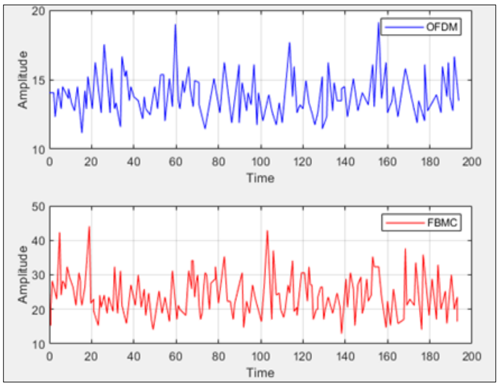

Figure 10. PAPR comparison showing the impact of filtering and overlapping operations on FBMC/OQAM signals

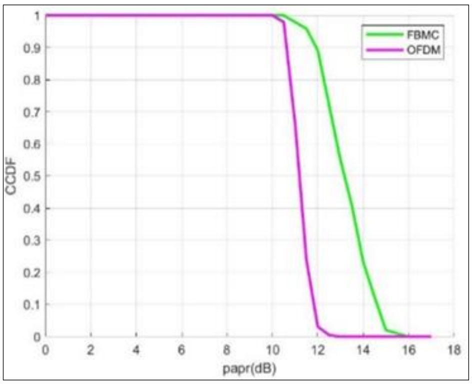

Figure 11. CCDF performance comparison between OFDM and FBMC/OQAM systems

In Table 5, a summary of all results has been illustrated in this paper. From an implementation perspective, OFDM maintains lower computational complexity due to the use of simple FFT/IFFT operations and single-tap equalization. In contrast, FBMC/OQAM requires synthesis and AFB as well as overlapping processing, which increases implementation complexity and processing latency. Nevertheless, the improved spectral efficiency and the lowered OOB emissions offered by FBMC/OQAM might justify this additional complexity in future wireless communication systems that require efficient spectrum usage.

Table 5. Performance comparison between OFDM and FBMC/OQAM systems

	OFDM	FBMC/OQAM	Comment
PSD	-28.6 at mid-point	-154 dB at mid-point	FBMC/OQAM achieves approximately 125 dB lower sidelobe levels, resulting in superior spectral containment and reduced OOB emissions.
Filter response	Decaying ripples from 10 to -0.14 dB	Decaying ripples from -4 to -50 dB	FBMC/OQAM exhibits faster sidelobe attenuation and improved spectral localization.
BER Vs. SNR	Comparable BER performance		Both systems achieve similar BER performance under identical channel conditions [12]
Channel estimation	For lower SNR gives high NMSE and for Higher SNR gives lower NMSE	E-IAM-C gives lower NMSE than IAM-C and IAM-R	E-IAM-C provides lower NMSE at low SNR values, whereas OFDM channel estimation exhibits improved performance at higher SNR values.
PAPR	PAPR is 2.7dB	PAPR is 4.9dB	OFDM achieves approximately 2.2 dB lower PAPR under the considered simulation conditions.
Spectral efficiency	Approximately 88.9% due to CP overhead	Approximately 100% due to CP-free transmission	FBMC/OQAM provides approximately 11% higher spectral efficiency due to the elimination of CP overhead.

5. CONCLUSION

In this paper, a comparative analysis between OFDM and FBMC/OQAM systems under the same simulation conditions was presented. The results obtained show that FBMC/OQAM achieves better spectral efficiency, lower OOB emissions, and improved spectral localization compared with OFDM due to the use of pulse-shaping filters and the removal of CP insertion. In addition, IAM-based channel estimation techniques, particularly E-IAM-C, provided improved channel estimation accuracy in FBMC/OQAM systems under multipath fading environments. On the other hand, OFDM maintained lower computational complexity and better PAPR performance under the simulated conditions. Therefore, the selection between OFDM and FBMC/OQAM depends mainly on the specific system requirements and performance constraints. Overall, FBMC/OQAM is a promising candidate waveform for future wireless communication systems that require improved spectral efficiency and interference mitigation capabilities. The presented unified comparative framework provides comprehensive insight into the performance characteristics of OFDM and FBMC/OQAM systems under identical simulation conditions, which can support waveform selection for future 5G and beyond wireless communication systems. Future work may involve deep learning-based channel estimation techniques, adaptive IAM schemes, MIMO-FBMC integration, and hardware implementation aspects for FBMC/OQAM systems in practical wireless communication environments.

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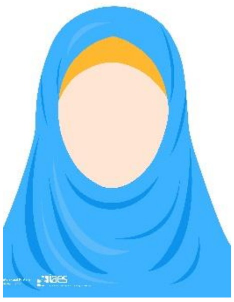

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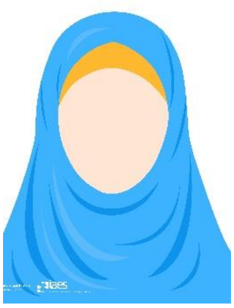

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