Performance Analysis of OFDM and FBMC

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Abstract. The purpose of this article is to compare the proposed 5G modulation techniques FBMC against OFDM which is the modulation technique used in 4G communications. In this article, we compare Spectral Density, Spectral Efficiency, PAPR, BER of FBMC and OFDM modulation techniques to analyze the merits of them. The simulation results show that FBMC has the lower BER, higher PAPR, greater Spectral Efficiency (if the burst is larger) and better performance of Spectral Density compared to OFDM modulation.

1. Introduction
Over the past decades, multicarrier communication techniques have been widely adopted in many communication systems for high data rate transmission [1]. Orthogonal frequency division multiplexing (OFDM) is certainly one of the most famous and accepted multicarrier technologies among the mainly wireless communication systems. However, the use of cyclic prefixes and guard bands to avoid too big sidelobes, results in a loss of 16% of spectral efficiency compared to theoretical performance [2]. Due to the abovementioned drawbacks in OFDM systems, the filter bank multicarrier with an offset quadrature amplitude modulation (FBMC/OQAM) system has recently drawn increasing attention from many researchers. FBMC/OQAM well utilizes time frequency localization (TFL) property pulse shaping via an IFFT/FFT-based filter bank, and staggered OQAM symbols, real symbols at twice the symbol rate of FBMC/QAM. Regardless of the higher complexity compared to OFDM, FBMC/OQAM can provide remarkably reduced out of band emissions, robustness against carrier frequency offset, and better spectral efficiency as CP is not required.

In this article, we compare FBMC modulation techniques against the existing OFDM technique by comparing Spectral Density, Spectral Efficiency, PAPR, BER of FBMC and OFDM modulation techniques to analyze the merits of them.

2. System model
In traditional FBMC systems, the maximum transmission rate can be achieved when the prototype filters of two adjacent symbols overlap in frequency domain. Therefore, the OQAM modulation is adopted to avoid intrinsic interference in the traditional system in this article. The Structure of FBMC-OQAM is shown in Fig 1.
In FBMC-OQAM system, the signal is modulated by QAM to become a complex signal, and then the real part and the imaginary part of the complex signal are taken respectively. The imaginary part of the signal is half a period later than the real part of the signal, and then it is converted into parallel signal by series-parallel conversion, so that the real part and imaginary part of each symbol are transmitted on subcarriers. After that, the signal is modulated by prototype filter and phase filter, and the final transmitted signal is superimposed by each subcarrier signal. At the receiving end, different channels are separated by spectrum shifting. Each signal is extracted from the real part and the imaginary part. After matched filter, the original phase is restored.

Suppose that the FBMC-OQAM system has $N$ subcarriers, which are modulated by OQAM and series-to-parallel conversion, it is converted into matrix $X = (X^0, X^1, X^m, ..., X^{M-1})$, $X^m, m$ denotes the $m$-th data block and $M$ denotes the symbol size.

$$X^m = (X_0^m, X_1^m, X_k^m, ..., X_{N-1}^m)^T$$

$k$ represents subcarrier index, $X_k^m$ represents data on the $k$ subcarrier and on the $m$ symbol block. $X_k^m = a_k^m + j b_k^m$, where $a_k^m, b_k^m$ represent the real and imaginary parts of the signal. $b_k^m$ lags $a_k^m T / 2$ in time domain, where $T$ represents symbol period.

The signal through the prototype filter $h(t)$ is represented as:

$$X_k^m(t) = [a_k^m h(t - mT) + j b_k^m h(t - T / 2 - mT)]e^{j \frac{\pi k}{2}}, k = 0,1, ..., N - 1$$ (1)

After $N$ subcarriers orthogonal modulation:

$$S_k^m(t) = [a_k^m h(t - mT) + j b_k^m h(t - T / 2 - mT)]e^{j \frac{\pi k}{2(T + 1)}}, k = 0,1, ..., N - 1$$ (2)

The signal on the $m$-th data block can be represented as:

$$S^m(t) = \sum_{k=0}^{N-1} S_k^m(t); mT \leq t \leq mT + L + \frac{T}{2}$$ (3)

$L$ denotes the length of the filter, where $L = KM$. Finally, $M$ data blocks are superimposed to get the final signal $S(t)$. 

**Figure 1.** Diagram of FBMC-OQAM system.
\[ S(t) = \sum_{k=0}^{M-1} S^m_k(t), 0 \leq t \leq MT + L - \frac{T}{2} \quad (4) \]

Combining Formula (2) and (4), we can get the Formula (5):

\[ S(t) = \sum_{m=1}^{M} \sum_{k=0}^{N-1} [a^m_k h(t - mT) + jb^m_k h(t - T / 2 - mT)] e^{j\frac{2\pi}{T}(n/2)k}, k = 0, 1, ..., N - 1 \quad (5) \]

3. Measurement

a) Spectral Density

The spectral density represents the strength of the signal over a time period (i.e) the possible bandwidth over which the bits can be sent successfully. A modulation’s spectral density is efficient if the strength is closer to the normalized frequency.

b) Spectral Efficiency

Spectral efficiency/ spectrum efficiency or bandwidth efficiency refers to the no. of bit that can be transmitted over a bandwidth. It is the information rate that can be transmitted over a given bandwidth in a specific communication system.

\[ \eta_{OFDM} = \frac{m \times N_{FFT}}{N_{FFT} + N_{CP}} \quad (6) \]

\[ \eta_{FBMC} = \frac{m \times S}{S + K - \frac{1}{2}} \quad (7) \]

c) PAPR

One of the major problems of FBMC-OQAM systems is high peak-to average power ratio (PAPR) of transmitted FBMC-OQAM signals. Since the high-power amplifier used in FBMC-OQAM systems has limited linear range, the FBMC-OQAM signals with high PAPR will be seriously clipped and nonlinear distortion will be introduced, resulting in serious degradation of the bit error rate performance. It plays a vital role in signal processing applications. The system is more efficient if the PAPR is less.

d) BER

BER represents the number of bit errors per unit time. It is an important parameter to characterize system performance.

4. Proposed work

The implemented project involves comparison of modulation techniques between OFDM and FBMC. The comparison involves simulating these modulations over different set of parameters. The results obtained includes measurements such as spectral efficiency, BER, PAPR and power spectral density. The implementation is performed using MATLAB.

Table 1. Parameters of OFDM and FBMC.

| Parameter            | OFDM | FBMC |
|----------------------|------|------|
| FFT                  | 512  | 512  |
| Bits per subcarrier  | 4    | 4    |
| Spreading Factor     | 4    |      |
| Cyclic prefix length | 64   |      |
5. Simulation result

![Power Spectral Density FBMC vs OFDM](image1.png)

**Figure 2.** Power spectral Density FBMC vs OFDM.

In Figure 2, the red shaded region represent the spectral density of FBMC while blue that of the OFDM. It can be seen from the above graph that the spectral density of FBMC is greater than that of the OFDM. When the normalized frequency is 0.2, the PSD of FBMC is 82dB lower than that of OFDM. The FBMC has the spectral density closest to the normalized frequency when compared to OFDM modulation.

![Spectral Efficiency FBMC vs OFDM](image2.png)

**Figure 3.** Spectral Efficiency FBMC vs OFDM.
Fig. 3 denotes the spectral efficiency of OFDM and FBMC. The graph is generated by varying the duration of burst from 0 to 200ms. It’s observed that the FBMC’s spectral efficiency increases with the increase in duration of bursts. It is greater than of bursts is larger. When the duration of burst is longer than 90ms, the spectral efficiency of FBMC exceeds that of OFDM.

Variation in the SNR affects the quality of the constellation. The simulation of BER vs SNR was generated for SNR from 0 to 15 dB in Fig. 4. As can be seen from the Fig 4, FBMC has the best performance compared to the OFDM system.

![SNR vs BER - FBMC and OFDM](image1)

**Figure 4.** BER of FBMC and OFDM.

![FBMC vs OFDM in PAPR](image2)

**Figure 5.** FBMC vs OFDM in PAPR.
Since OFDM and FBMC are special forms of multi-carrier modulation technology, making them inevitably produce high PAPR. As can be seen from Fig 5, FBMC has higher PAPR than OFDM. Higher peak-to-average power ratios can cause severe power consumption. Therefore, it is of great significance to study the PAPR suppression algorithm.

6. Conclusion
The goal of the article is to obtain a performance analysis of different modulation schemes FBMC and OFDM implemented in 5G communications. This helped in obtaining the efficiency of the modulation techniques considering parameters like PAPR, BER, Spectral Density and Spectral Efficiency. According to the above simulation results, compared with OFDM system, FBMC has lower bit error rate, higher spectrum efficiency and higher PAPR. In the following research, we will focus on the suppression algorithm of PAPR in FBMC system.

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