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Performance Evaluation of FBMC, UFMC, and F-OFDM Modulation for 5G Mobile Communications

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ABSTRACT
This paper presents the performance evaluations of the multicarrier modulation systems such as the Filter Bank Multicarrier (FBMC), the Filtered Orthogonal Frequency Division Modulation (F-OFDM) and the Universal Filtered Multicarrier (UFMC). The performance evaluation of these new waveform candidates for 5G mobile communications has been performed based on Power Spectral Density (PSD) and Peak to Average Power Ratio (PAPR) using MATLAB Version 2019. Simulation results show that, compared to the Frequency Division Modulation (OFDM), FBMC could be a more effective solution.
KEYWORDS: *5G, FBMC, Multicarrier, F-OFDM, OFDM, UFMC*

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I. INTRODUCTION

Recently, the data consumption is expected to increase by 30% which cannot be supported by the current technologies such as 3G and 4G. Hence, there is a need of next generation wireless communication system. The rollout of a 5G wireless communication system is taking place all around the world. 5G is expected to be commercially available this year. At the same time, there is huge increasing demand from industries, health sectors and educational sectors to utilize the advantage of wireless communication. Such innovation will give motivation to Internet of Things (IOT) [1, 2]. Till now, 5G is not defined; however, it may be the integration of several wireless techniques [1].

Currently, Code-Division Multiple Access (CDMA) and Orthogonal Frequency Division Modulation (OFDM) are the modulation techniques used in 3G and 4G mobile communication system. Inter-Symbol-Interference (ISI) and high-power consumption were certain disadvantages of CDMA [1, 3]. CDMA was used in a 3G system which was replaced by OFDM due to several advantages of OFDM like ease of implementation, immunity to interference, high data-rate, etc. But OFDM also possesses certain disadvantages like use of Cyclic Prefix (CP), a large side lobe which limits the utilization of spectrum. Additionally, Peak to Average Power Ratio (PAPR) is also considered to be one of the biggest hurdles in OFDM which greatly reduced the performance and efficiency of non-linear OFDM amplifier. For instance, the loss of bandwidth due to the cyclic prefix is about 9% in Wi-max. Therefore, OFDM is not likely to be considered for next generation mobile communication system. Hence, many researchers are exploring better modulation techniques that can be suitable for 5G [1, 4].

Multicarrier modulation has marked its importance over the past several decades for the realization of broadband communication systems. Based on sending parallel streams of information in the frequency domain on different center frequencies, multicarrier modulation has exhibited its potential to transmit large amounts of data across a channel while improving the robust of the communication system against various impairments [5]. Among the existing multicarrier modulation systems, we can cite the Filter Bank Multicarrier (FBMC), and the Universal Filtered Multicarrier (UFMC), and the Filtered Orthogonal Frequency Division Modulation (F-OFDM).

The FBMC is an alternative transmission method that resolves the above problems by using high quality filters that avoid both ingress and egress noises. Also, because of the very low out-of-band emission of subcarrier filters, application of FBMC in the uplink of multiuser networks is trivial [6, 7]. It can be deployed without synchronization of mobile user nodes signals. In the application of cognitive radios, the filter bank that is used for multicarrier data transmission can also be used for spectrum sensing [8-10]. On the other hand, compared to OFDM, FBMC falls short in handling Multiple-Input Multiple-Output (MIMO) channels, although a few solutions to adopt FBMC in MIMO channels have been reported in the literature [6, 11]. Nevertheless, as the recent research study has shown, FBMC is found as powerful as OFDM and in some cases superior to OFDM in the emerging area of massive MIMO [6].

UFMC is a recent proposal where a group of subcarriers is filtered to reduce the Out of Band (OOB) emission. Because the bandwidth of the filter covers several subcarriers, its impulse response can be short, which means that high spectral efficiency can be reached in short burst transmissions. Since UFMC does not require a CP, it is possible to design the filters in order to obtain a total block length equivalent to the CP-OFDM. However, because there is no CP, UFMC is more sensitive to small time misalignment than CP-OFDM [12].

The unfavorable spectrum confinement property of OFDM is due to the usage of rectangular pulses whose Power Spectrum Density (PSD) in the frequency domain is a sine function. The F-OFDM filters the subcarriers to achieve much smaller OOB leakage while maintaining strict separation of the signals in the time domain and the complex field orthogonality. The major advantages of F-OFDM are a fast roll-off rate and a full capability of adapting various 5G requirements with flexible choices of filter design when good frequency localization is needed [13].

The goal of this paper is to study FBMC, UFMC and F-OFDM multi-carrier modulations and compare them to OFDM in terms of specific performance features such as PSD and Peak-to-Average Power Ratio (PAPR). The rest of the paper is organized as follows: the key technologies in 5G are presented in Section 2. Numerical results are analyzed in Section 3. Finally, the last section draws some conclusions.

II. KEY TECHNOLOGIES IN 5G

II.1 OFDM

OFDM is a popular multi-carrier waveform format developed for RF systems and applied in Long-Term Evolution (LTE) downlink. It can significantly increase the data rate in bandwidth-constrained channels with high spectral efficiency and allow efficient MIMO integration. Furthermore, the robustness of OFDM to either phase noise or time-selective channels depends on the spacing of its subcarriers [14].

The principle of the frequency multiplexing is to group numerical data per packages of N, which is called OFDM symbol, and to modulate each data by a different carrying at the same time. Let us consider a sequence of N data (c_0 , c_1 ,. . ., c_{N-1}) and the time T_s which separates 2 sequences from N data. In each data there is c_k module with a signal at the frequency f_k. The individual signal is written in a complex form: $c_k e^{2j\pi f_k t}$. The total signal $s(t)$ corresponding to the whole N symbols is:

$$s(t) = \sum_{k=0}^{N-1} c_k \, e^{2j\pi f_k t} \, . \tag{1}$$

If the space between the frequencies is $1/T_s$, the multiplexing is orthogonal and then $f_k = f_0 + \frac{k}{T_s}$. Therefore, the total signal $s(t)$ can be written as:

$$s(t) = e^{2j\pi f_0 t} \sum_{k=0}^{N-1} c_k \, e^{2j\pi \frac{kt}{T_s}} \, . \tag{2}$$

We note that the numerical data c_k are complex numbers which have binary characters by a mapping of Quadrature Amplitude Modulation (QAM) in several states (4, 16 and 64, in general, 2^q states). These data are q^{th} symbols formed by the grouping of q bits.

II.2 FBMC

FBMC, which is an evolved version of OFDM, overcomes the limitations of OFDM by adding generalized pulse shaping filters which delivers a well-localized subchannel in both time and frequency domain. Consequently, FBMC systems, as a promising waveform format for 5G, have more spectral containment signals and offer more effective use of the radio resources where no CP is required. Hence, its associated spectral efficiency is higher than that of OFDM. In addition, the half-Nyquist prototype filters mitigate ISI and the Offset Quadrature Amplitude Modulation (OQAM) removes Inter Carrier Interference (ICI). The fact that FBMC uses a subcarrier filtering makes the following advantages: the filter length is long (high latency), the OOB emission is reduced, and the isolation between the subcarriers increases (high robustness to time-selective channels). However, a complex method is needed to estimate and compensate the channel. Therefore, MIMO integration with FBMC is more difficult. It is worth noting that FBMC can also employ scalable numerology [14].

II.3 UFMC

UFMC is the method that combines the advantages of orthogonality OFDM and filter bank in FBMC. Instead of filtering each carrier like in FBMC, a group of subcarriers (called subband) is filtered. The filter parameters and number of carriers per subband are typically common, which prevents aliasing. Nonetheless, non-contiguous subbands are possible to allow flexible utilization of the available spectrum. Therefore, UFMC can be considered as a compromise between OFDM and FBMC [15].

II.4 F-OFDM

F-OFDM is very similar to UFMC, as it creates multiple subbands. But it is based completely on the existing OFDM numerology. The main idea is to apply additional steps that are not considered in classic OFDM like a subband specific filter and to allow the parameterization of the numerology in a more flexible way. A major difference to UFMC is that it allows completely different parameters for each subband for the subcarrier spacing, length of CP and transmission time interval. Subband-based filtering then suppresses the inter-subband interference [15].

III. Numerical results and Discussion

One of the key issues with any 5G modulation scheme is the spectral efficiency. With spectrum being at a premium, especially in frequencies below 3 GHz, it is essential that any modulation scheme adopted for 5G is able to provide a high level of spectral efficiency.

The power spectral density is defined as the square of the module of the Fourier transform divided by the bandwidth spectral, which is the inverse to the time of integration T. More rigorously, PSD average is the limit when T tends towards infinite expectation of the module square of the Fourier transform of the signal. Thus, if x is a signal and X its Fourier transform, the power spectral density is expressed by

$$\Gamma_x = |X(f)|^2/T. \tag{3}$$

It represents the frequency distribution of the power of a signal.

First, the parameters used to determine the PSD in OFDM and FBMC are the followings: number of Fast Fourier Transform (FFT) points 1024, guard bands 212, factor of overlapping $K = 4$, number of symbols 100, mapping symbol 2 (4QAM), and Signal to Noise Ratio (SNR) 12 dB. Figure 1 presents the PSD for OFDM (blue-dotted line) and FBMC (purple-dashed line) modulations. It is shown that the PSD of OFDM is equal to -30 dB while that of FBMC is -165 dB. Hence, there is a lot of OOB power leakage in OFDM compared to FBMC. We notice that when $K = 3$, the PSD of FBMC becomes -155 dB and when $K = 2$, that of FBMC becomes -50 dB. Therefore, the decrease of the K value leads to an increase of the PSD value. Form this result, we obtain the degradation of the transmission.

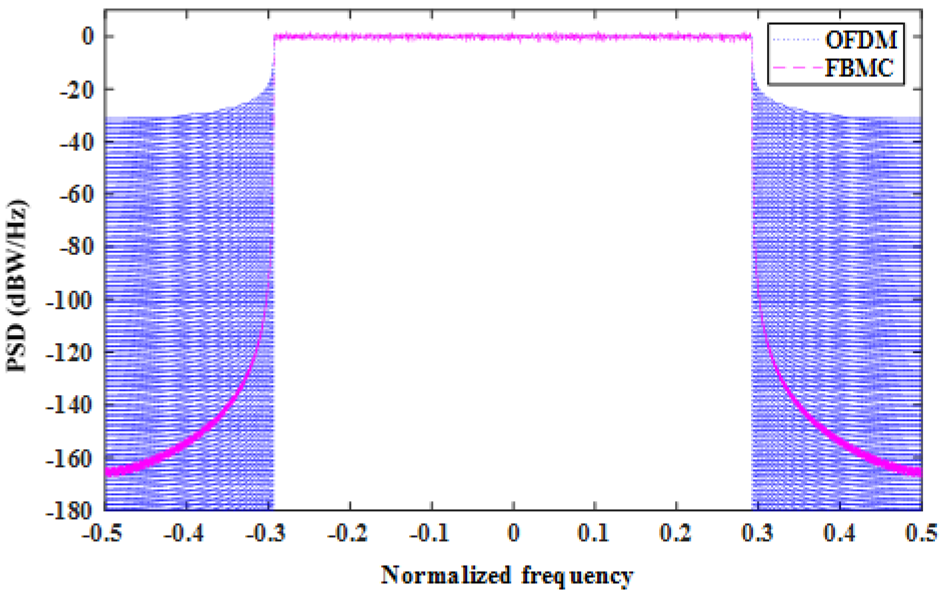

Figure 1. PSD comparison between OFDM (blue-dotted line) and FBMC (purple-dashed line).

Second, the parameters used to determine the PSD in OFDM and UFMC are the followings: number of FFT points 512, bands of subcarriers 20, number of subbands 10, offset of subband 156, filter length of Dolph-Chebychev 43, attenuation of the side lobes 40 dB, mapping of subcarrier 4, number of symbols 100, and SNR 15 dB. Figure 2 presents the PSD for OFDM (blue-dotted line) and UFMC (purple-dashed line) modulations. Numerical simulations give the PSD value of -30 dB for OFDM and -80 dB for UFMC. Therefore, UFMC exhibits less OOB power leakage and less power required to transmit the UFMC signal compared to OFDM.

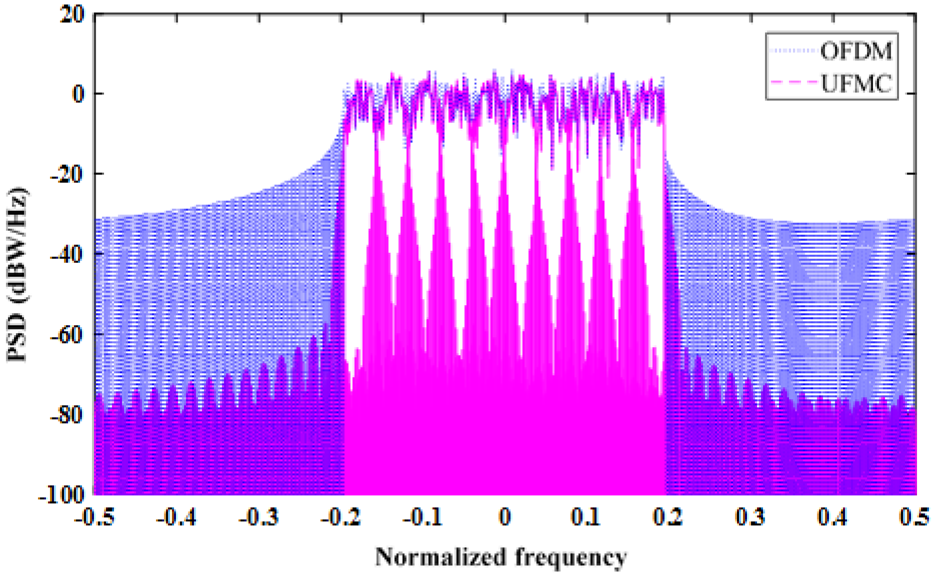

Figure 2. PSD comparison between OFDM (blue-dotted line) and UFMC (purple-dashed line).

Lastly, the data used to determine the PSD in OFDM and F-OFDM are the followings: number of FFT points 1024, number of resource blocks 50, number of subcarriers per resource block 12, CP length 72, mapping symbol 6, tone offset 2.5, filter length 513, and SNR 18 dB. Figure 3 presents the PSD for both OFDM (blue-dotted line) and F-OFDM (purple- dashed line) modulations. The obtained PSD is -65 dB for OFDM and -180 dB for F-OFDM. It is seen that F-OFDM modulation has a lower PSD than OFDM. Therefore, F-OFDM exhibits less power leakage than OFDM.

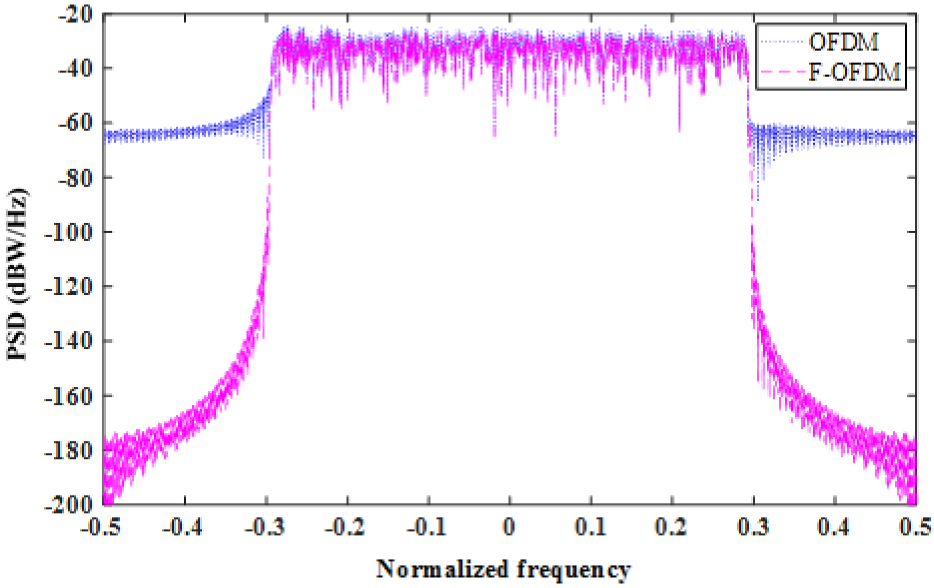

Figure 3. PSD comparison between OFDM (blue-dotted line) and F-OFDM (purple-dashed line).

The peak factor is a measurement characteristic of a signal. It is the relationship between the amplitude of the peak of the signal and the effective value of the signal. It is usually correlated with the Peak-to-Average Power Ratio (PAPR) which indicates a relationship between power peak and average power. The PAPR is one aspect of performance that needs to be considered for any 5G communication modulation scheme. It also has a major impact on the efficiency of the power amplifiers. The mathematical evaluation of PAPR is defined as

$$PAPR = \frac{Peak\ Power}{Average\ Power} \tag{4}$$

PAPR		PAPR		PAPR	
OFDM	9.0871 dB	**OFDM**	8.8843 dB	**OFDM**	9.7219 dB
FBMC	8.8375 dB	**UFMC**	8.2379 dB	**F-OFDM**	11.371 dB

Table 1. PAPR comparison between FBMC, UFMC, F-OFDM to OFDM.

The table 1 presents a comparative study of the various modulations in terms of PAPR. As we can see in table 1, OFDM has a higher PAPR value than FBMC. This practically translates into the need for having a more powerful amplifier for the emission of OFDM signal. Regarding to the UFMC, it also presents a lower PAPR value than the OFDM and thus requires less power with the emission than the OFDM. Lastly, F-OFDM presents higher PAPR value than the OFDM. This implies a higher transmission power and therefore, a much more powerful radio amplifiers with the consequence of reducing the battery life.

IV. Conclusion

In summary, we have evaluated the performances of new waveform candidates such as FBMC, UFMC and F-OFDM for 5G mobile communication systems. We have specifically simulated some key parameters, the power spectral density and the peak to average power ratio, needed for 5G. We have shown that a power spectral density of the three candidates is lower than that of OFDM. In addition, we have compared their peak to average power ratio. It is confirmed from all numerical results that PAPR of three waveform candidates is higher than that of OFDM except the case of F-OFDM.

Due to its simplified architecture and the obtained values of PAPR and PSD, the FBMC appears to be the best compromise. Nevertheless, a complete performance evaluation requires the determination of the Bit Error Rate in Additive White Gaussian Noise AWGN as well as the Rayleigh and Rician Fading Channel, with considering the complementary cumulative distribution function.

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