Universal-Filtered Multi-Carrier: A Waveform Candidate for 5G

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Abstract

The emerging Internet of Things will make the next generation 5G systems to support a broad range of diverse needs with greater efficiency requirements. The new class of services will need a higher data rates, to handle these demands, the lowest layer of the 5G systems must be flexible. Therefore, the waveform will have an important role in offering these new requirements. These waveforms should enable efficient multiple access to handle the requirements of the future wireless communication system. This means that the corresponding required waveforms should be able to handle as much different type of traffic as possible in the same band. In this paper we compare three candidate multicarrier waveforms for the air interface of 5G: the original cyclic prefix OFDM applied in the 4G systems today, the Filter Bank Multicarrier (FBMC) heavily discussed in previous papers, and Universal Filtered Multi-Carrier (UFMC) a new contender making its appearance recently. These new waveforms will be more robust against the time frequency synchronization problem, it has the potential for mixing different traffic specifications, and supports the scenarios of spectrum fragmentation, due to the improvement in the localization of spectrum. In the same time, they support all multiple input and multiple output (MIMO) scenarios and applications. The simulation results shown that there is a good difference in the time frequency efficiency for transmitting very small bursts where the response time is required (like car-to-car communications). Due to the cyclic prefix the FBMC and CP-OFDM suffer when transmitting short bursts, the UFMC outperforms CP-OFDM by 10% for any case and FBMC for the very short packets and it is similar to FBMC for long sequences. Other simulation results are shown, which demonstrate the potential of this waveform.

Keywords: 5G; OFDM; LTE; spectral efficiency; Cyclic Prefix;

1. Introduction

The 4G systems, LTE, use the OFDM technique which is considered as an elegant solution to face the frequency selective problem and to improve the efficiency of the spectrum [1]. CP-OFDM is the most known and applied for multicarrier systems, where the modulation is based on the IFFT, and symbols are guarded by the use of Cyclic Prefix (CP). The 4G LTE standard arrived sometime around 2010 and offered new services worldwide, like wireless broadband data service, which is considered as an important innovation in the digital wireless communication systems. Since approximatively every ten years, a new generation is introduced to meet spectral specifications and the increasing in the data rates requirements, the industry should ask about the future applications and where LTE has fall short to meet the requirements. In the introduction of the new 5G standard, some new multicarrier schemes have gained high attraction as a potential candidate. Indeed, UFMC is a promising contender since it has some advantageous characteristics, where the filtering process is applied on a per sub-band basis. The subcarriers are shaped by a sinc-filter in frequency domain or instead of sinc-shapes they have a more suitable form according to the filter design with reduced side-lobe levels [2]. With the Internet of Things (IoT) being served by a 5G system, the characteristics of the bursts to be transported and of the nodes connected to the network are much more varying in various aspects: Packet size, required response time, packet frequentness, device capabilities, and number of devices just to name a few. It becomes clear that the waveform of 5G should offer but not only the following: 1. Dedicated services for different needs and characteristics of channel, 2. Emission with reduced out of band, 3. tolerance to misalignment in the time-frequency [3, 4]. The objectives targeted by the European Union METIS project are to provide, at the 2020 horizon, 1000 times more mobile data volume per area, 10–100 times more connected devices, 10–100 times higher user data rates, 10 times longer battery life for low-power massive machine communication, and 5 times reduced end-to-end latency [5]. All these increases will be possible only by combining several factors: better usage of the available spectrum, use a new spectrum (above 6GHz), small cells generalization, introduction of massive MIMO, ... In addition to that there is a need to define a new air interface. The 4G system is based on CP-OFDM modulation which has two main drawbacks - a bad spectral confinement and a flexibility lack in the waveform - which are serious in the perspective of multi-services offered by the future 5G communication system. Dynamic spectrum aggregation is necessary to get an optimum usage of the available bandwidths below 6 GHz [6], the CP-OFDM based approach suffers from a high emission in the Out Of Band (OOB) and also from the granularity of the resource block which affects the allocation of a single subcarrier to low data rate communication services. And there are other problems which may also occur with frequency shifts due to Doppler effects in the case of the high mobility applications. As mentioned by Wunder et al. [7], obtain a significant reduction in the latency is a problematic in CP-OFDM. In addition, to the spectral efficiency reduction when the cyclic prefix is used to avoid interference problems. For all these reasons, if is urgent to design a new system based on good flexibility of the waveform which can solve the challenges of 5G in its physical layer. In this paper, we analyze and compare the waveform contenders: The Universal Filtered Multi-Carrier (UFMC) and the Filter Bank Multicarrier (FBMC) to CP-OFDM with respect to their probability of error when changing some parameters mentioned later on.

The remainder of this paper is organized as follows. In Section II, we introduce the three waveforms to be compared – CP-OFDM, Universal Filtered Multi-Carrier (UFMC), and the Filter Bank Multi-Carrier (FBMC). Section III presents the block diagrams of these three systems. The comparison metrics, like the time frequency efficiency, are also presented in Section IV. The system performance is investigated in Section V through extensive trace-driven simulation. Finally, conclusions are given in Section VI along with the suggestions for future work.

2. Theoretical Background

Without any discussion, CP-OFDM became the reference Multi Carrier Modulation (MCM). In the same time, two variants with a lower degree of maturity was available, the filtered multi-tone (FMT) and the filter bank multi-carrier (FBMC). More recently, a new scheme named FOFDM is also entering the debate for the fifth generation. Instead to be filtered subcarrier by subcarrier the new one correspond to be sub-band filtered. In this section, we briefly go through this list of waveforms and to be complete we will present the basic CP-OFDM. But before, we will define some parameters used in the formulation below:

M: Maximum number of subcarriers = Size of the (I)FFT)
K: Number of sub-symbols in the case of block transmission
T_s: Sampling period which is considered here as unity
T: Duration of each single OFDM symbol
c: Symbol transmitted over each carrier in complex constellation
a: Symbol transmitted over each carrier in real valued constellation

2.1 Orthogonal Frequency Division Multiplexing

The fundamental advantage of OFDM is the usage of subcarriers overlapped to modulate parallel data streams, which makes it more efficient in bandwidth efficient than the conventional technique. These subcarriers need to be orthogonal, to avoid the inter-carrier interference. The fast Fourier transform (FFT) is used to derive this set of orthogonal subcarriers. By modulating low rate data streams onto these subcarriers, OFDM system can ensure flat fading condition on each subcarrier. OFDM is a simple MCM technique which is widely used in many applications, in a single carrier modulation the transmitted data occupies the entire available bandwidth, the OFDM data are modulated over a number of narrow subcarriers each of them has a bandwidth smaller than the coherent bandwidth of the channel, giving an approximately flat fading channel at each subcarrier. In addition, a cyclic prefix is inserted after each symbol, which is a copy of a certain number of samples from the tail, with L_{cp} is its length. This further improves the flatness of the channel at each subcarrier, which enhances the robustness against the frequency selectivity of the channel. In OFDM, the transmission is done symbol-by-symbol which means that K=1, so the baseband symbol of CP-OFDM is expressed, for $k\in[-L_{cp}, M-1]$, as

$$s_{CP-OFDM}(k)=\sum_{m=0}^{M-1} c_m e^{\frac{j2\pi mk}{M}} \tag{1}$$

where c_m are the transmitted complex symbols at each subcarrier m, like QAM constellations. The overall operation can be realized by FFT and IFFT. One of the advantage of CP-OFDM is maintaining the orthogonality for the transmission over channel which is dispersive in time. Consequently, a simple method for channel estimation and equalization is used to recover orthogonality at the receiver. However, the rectangular pulse used in CP-OFDM has several disadvantages, so, implicitly the pulse shaping will be realized by the Fourier transform.

2.2 Filter Bank Multi-Carrier

The introduction of structured transmission is the remarkable contribution of FBMC, which allow the system to escape the Balian-Low theorem requirements [8]. The FBMC technique employ a better pulse shape, keeping the orthogonality, and transmitting at the Nyquist rate. In OFDM technique we transmit complex symbols at subcarriers, but in the structured technique we transmit the real and imaginary parts of the complex symbols separately with a half symbol duration delay, $T/2$. Better details of FBMC concept is in Le Floch et al. and [9]. The baseband signal in FBMC can be presented, for any integer k, as in [10]:

$$s_{FBMC}(k) = \sum_{n \in Z} \sum_{m=0}^{M-1} a_{m,n} \underbrace{g(k - nN_1) e^{j\frac{2\pi}{M}mk} e^{j\phi_{m,n}}}_{g_{m,n}(k)} \tag{2}$$

with g the filter, $N_1 = M/2$ the offset of the discrete-time, $\varphi_{m,n}$ an additional phase term at subcarrier m and symbol index n, which can be expressed as $\pi/2(n+m)$. $a_{m,n}$ the real value of the transmitted symbols, and obtained from the real and imaginary parts of a QAM constellation. For perfect reconstruction, the filter g must satisfy the orthogonality condition:

$$\Re\left\{\sum_{k \in Z} g_{m,n}(k).g^*_{p,q}(k)\right\} = \delta_{m,p}\delta_{n,q} \tag{3}$$

where $*$ is the complex conjugation, $\delta_{m,p} = 1$ if $m = p$ and $\delta_{m,p} = 0$ if $m \neq p$.

As plain OFDM, FBMC takes advantage of fast IFFT/FFT algorithms. But, it has an extra complexity compared to OFDM. This complexity comes from the fact of working with half duration real symbols which means performing the IFFT/FFT at twice rate, and from the additional blocks of filters. This additional complexity depends on the selected scheme in the implementation.

2.3 Universal Filtered Multi-Carrier

In the UFMC case the total available bandwidth is partitioned into B sub-bands; each sub-band is separately modulated using classical OFDM modulation [11]. Then a FIR filtering of length L is applied to each sub-band modulated signal. Finally, the UFMC signal is a summation of B filtered sub-band modulated signals. For each resulting block of length $L+M-1$, the baseband UFMC signal can be written, for $k \in [0, M+L-1]$, as follows:

$$s_{UFMC}(k) = \sum_{i=1}^{B} \sum_{l=0}^{L-1} \sum_{m=0}^{M-1} c^i_m e^{j\frac{2\pi(k-l)m}{M}} f_i(l) \tag{4}$$

with c^i_m the complex-valued symbols for subcarrier m and sub-band i. Note that in the UFMC proposal, the definition of sub-band is imposed as one physical resource block (PRB).

As the successive blocks do not overlap, for a back-to-back system, orthogonality in time is ensured, while orthogonality in frequency depends on the precise features of the filter being used. Note also that the transition interval between consecutive blocks, resulting from filtering, plays the role of a guard interval and protects the transmitted symbols as long as L is greater or equal to the maximum delay spread introduced by a multipath channel.

However, concerning the implementation aspects, one has to refer to a more recent publication [12], which proposes a realization scheme that outperforms the one resulting from a direct implementation based on equation (4). Nevertheless, it appears that even with this later implementation scheme, the extra cost compared to a CP-OFDM reference goes up at least to a factor two in the uplink case, assuming the usage of a minimum number of resource blocks, and up to eight or ten for the downlink.

3. Systems Models

3.1 CP-OFDM

In a digital domain, binary input data (bits) are collected and coded with a channel coding schemes such as convolutional codes. After that the coded bit stream is interleaved to obtain diversity gain. Afterwards, a group of interleaved bits are grouped together (1 for BPSK, 2 for QPSK, 4 for 16QAM, ...) and mapped with the corresponding points in the constellation. At this instant, the data in complex numbers representation and they are in serial. So, the known pilot symbols mapped with known mapping schemes can be inserted at this time, and we obtained the modulated data stream mentioned in the Figure 1. After applying a serial to parallel converter, the IFFT operator is performed on this parallel complex data. The transformed data is grouped together again, as per the number of required transmission subcarriers. Cyclic prefix is inserted in every block of data according to the system specification and the data is multiplexed to a serial order. Here, the data can be considered OFDM modulated and ready to be transmitted. A Digital/Analog Converter (DAC) is used to transform the digital data to time domain analog data. RF modulation is performed and the signal is up-converted to transmission frequency. When transmitted by the antenna, the OFDM signals go through all the impairments of the wireless channel.

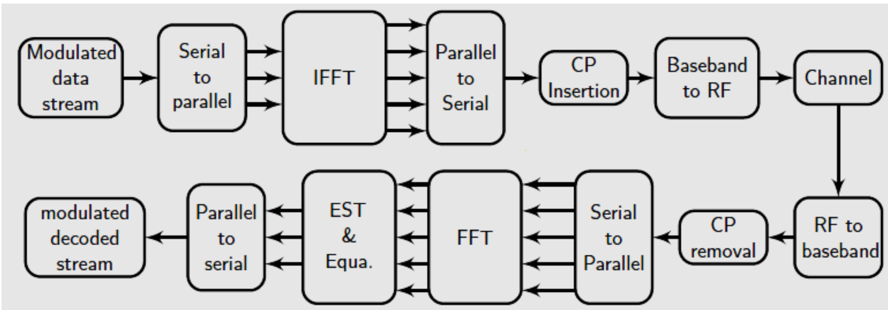


Figure 1. CP-OFDM transceiver scheme.

At the receiver, they will be down-converted and reconverted to digital using an Analog/Digital converter (ADC). We should make attention to frequency offset due to channel and mobility, so a carrier frequency recovery should be performed when the down-conversion operation is working. After the digitization process, the symbol timing synchronization is achieved. Then the FFT operator is used to demodulate the OFDM signal. After that, channel estimation is performed using the demodulated pilots. Using the estimations, the complex received data is obtained which are de-mapped according to the transmission constellation diagram. At this moment, FEC decoding and de-interleaving are used to recover the originally transmitted bit stream. The CP-OFDM is the most commonly known and applied multicarrier format (in 3GPP LTE and IEEE 802.11).

3.2 FBMC

The simple block diagram shown in Figure 1 can be adapted to implement the filter bank, it is just sufficient to extend the IFFT and the FFT. In section 3.1, a data stream is applied to one input of the IFFT and it modulates one carrier. In a filter bank with overlapping factor *K*, as shown in Figure 3 a data stream modulates 2*K*-1 carriers. Thus, the filter bank in the transmitter can be implemented with an extended IFFT of size KM, to generate all the necessary carriers; and each data element, after multiplication by the filter frequency coefficients, is sent to the ($2K$-1) inputs of the IFFT from $(i-1)K+1$ to $(i+1)K-1$. So, the data element is spread over several IFFT inputs, as shown in Figure 2. For each set of input data, the output of the IFFT is a block of KM samples and, since the symbol rate is $1/M$, K consecutive IFFT outputs overlap in the time domain. Therefore, the filter bank output is provided by an overlap and sum operation, as shown in Figure 3.

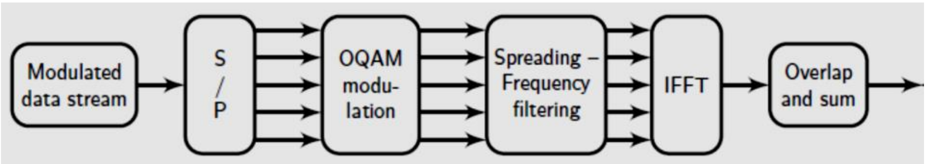


Figure 2. FBMC transmitter scheme.

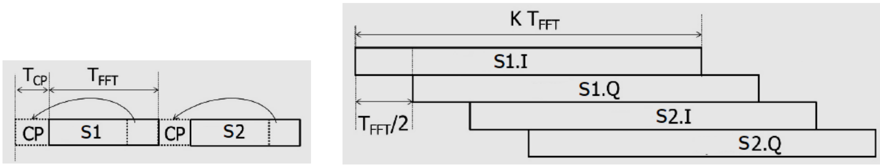


Figure 3. CP-OFDM vs FBMC frames.

The implementation of the receiver is also based on an extended FFT, of size KM. In that case, the FFT input blocks overlap, it is the classical sliding window situation. At the output of the FFT, the data elements are recovered with the help of a weighted de-spreading operation. In fact, the data recovery rests on the property of the frequency coefficients of the Nyquist filter. The delay of the whole system, when the transmitter and the receiver are connected, is KM samples, or K multicarrier symbols.

A remarkable feature of the scheme presented in Figure 2 is its simplicity: it is just the scheme shown in Figure 1 completed by minor operations before and after the IFFT/FFT. In fact, the key difference is the complexity, due to the increasing of the FFT size from M to KM. Due to the overlapping in the time domain of the IFFT outputs and FFT inputs, a lot of redundancy is present in the computations which can be reduced by using certain scheme or idea.

3.3 UFMC

UFMC applies filtering to subsets of the complete band instead of single subcarriers or the complete band. Figure 4 depicts an UFMC transmitter with B sub-bands (single antenna case). The i-th UFMC sub-module, with $i \in \{1,2, ..., B\}$, generates the $(N+N_{filter}-1)$-dimensional time-domain baseband vector x_i following the UFMC design criteria for the respective sub-band carrying the complex QAM symbol vector s_i with dimension $n_i \times 1$. N is the required number of samples per symbol to represent all sub-bands without introducing aliasing (N depends on the overall covered bandwidth), the sample rates of the single sub-bands naturally have to be aligned to each other, N_{filter} the length of the filter.

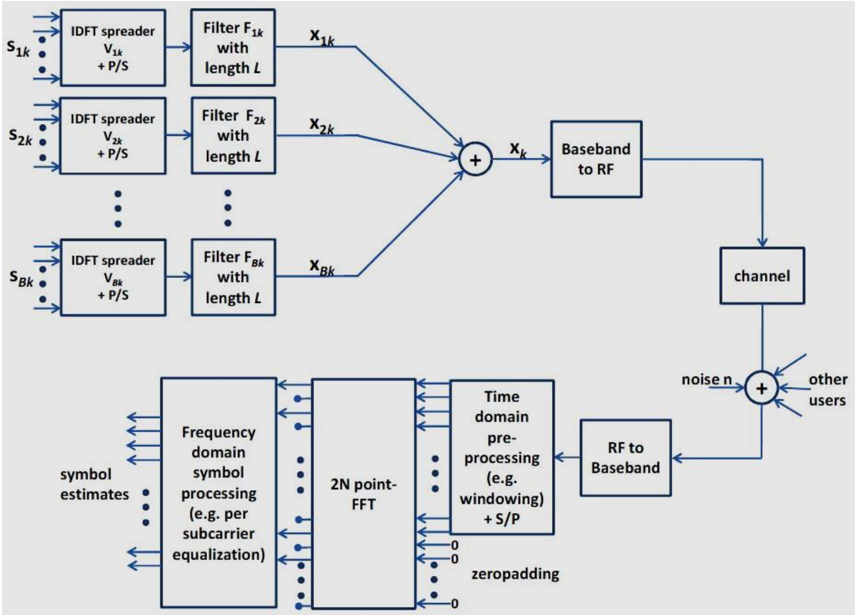


Figure 4. UFMC transceiver.

We consider one multi-carrier symbol out of a consecutive stream of symbol vectors, dropping the temporal symbol index for the ease of notation. The single sub-band signals are combined to synthesize the transmit vector x. In case of downlink (DL) the single sub-modules cover the complete available frequency band(s), transporting data to multiple users. In uplink (UL) the single sub-modules cover only the frequency portion the respective user has been allocated to. The n_i complex QAM symbols are transformed to time-domain using an IDFT spreader. Then the sub-band filter is applied.

The choice of B depends on the spectral settings the UFMC transmitter has to deal with and on the system design targets. If the system is to be applied to a scenario with fragmented spectrum, B may be chosen according to the number of available spectral sub-bands (B may even vary in time in case of some of the spectral sub-bands being populated by other wireless services only occasionally).

4. Comparison Metrics

In this section, we provide a comparison of the different waveform presented in this paper. The comparison includes several metrics: the spectral efficiency, the tail issue, the spectrum confinement, the mobility, the latency, the complexity, and the compatibility with 4G (LTE). This comparison is necessary to provide a global view of the advantages/drawbacks of schemes.

4.1 The Spectral Efficiency

The spectral efficiency analysis for part of the 5G waveforms is done by Lin and Siohan. CP-OFDM cannot achieve this maximum value due to the addition of a CP of length TCP. This leads to an overall efficiency reduction:

$$\eta_{CP-OFDM} = \frac{T}{T + T_{CP}} < 1 \tag{5}$$

In contrast, the FBMC scheme respects the Nyquist rate and no CP is used. Hence it is possible to achieve the maximum efficiency:

$$\eta_{FBMC} = \frac{1}{T.F} = 1 \tag{6}$$

Where F is the spacing between subcarriers, The maximum efficiency for an orthogonal system is reached when: $T.F=1$.

Finally, The UFMC scheme does not imply any CP. But nevertheless, a zero-padding is employed after OFDM modulation, which ensures an isolation between consecutive symbols after time-domain FIR filtering. The number of padded zeros is equal to the FIR filter length minus 1, making the overall spectral efficiency the same as CP-OFDM:

$$\eta_{UFMC} = \frac{1}{(T + T_{ZP}).F} = \frac{T}{T + T_{CP}} < 1 \tag{7}$$

where T_{ZP} is the zero-padding duration, which is equal to T_{CP} of the CP-OFDM case.

4.2 The Time-Frequency Efficiency

The time-frequency efficiency η_{tf} is defined as follows: $\eta_{tf} = \eta_f.\eta t$, where η_t is the efficiency in time direction relating the information carrying body of the burst to its overall length including the tails, and η_f is the efficiency in frequency direction relating the number of usable subcarriers to the overall number of subcarriers within the usable band.

In a later publication the time-frequency efficiency will be extended taking realistic transmission aspects into account. In conclusion, UFMC outperforms CP-OFDM for any setting by about 10% and brings additional benefits such as higher robustness to time and frequency misalignments and improves spectral properties. FBMC is very efficient with long bursts. However, the time-frequency efficiency degrades significantly in case of small burst in contrast to UFMC and CP-OFDM. So, UFMC is the best choice for a system targeting to include an option for short burst transmissions into the overall design.

4.3 The Tail Issue

In a burst transmission, the tail issue mainly reflects the potential overlap between two bursts, which means symbols are not completely isolated in the time domain but instead part of the symbols is overlapped. This issue has been identified for the FBMC scheme. In CP-OFDM, each symbol is completely isolated in the time domain so that it does not have any tail issue. The UFMC controls the filter length and utilizes zero padding to absorb the filtering tails. UFMC has similar properties to OFDM in this respect: each UFMC symbol is completely isolated in the time domain so that it does not have any tail issue.

4.4 The Spectrum Confinement

Two main problems with CP-OFDM lead to bad spectrum confinement: Spectral leakage due to the waveform discontinuity, and the rectangular pulse shape for CP-OFDM. The first problem can be solved when the envelope of the symbol edges is smoothly decreasing to zero. To solve the second one in FBMC, the rectangular filter is replaced with a prototype filter that has good frequency localization and a length longer than the FFT size. For UFMC, the discontinuity issue can be overcome by FIR filtering. However, the improvement in spectrum confinement is less than for FBMC.

4.5 The Mobility

Mobility robustness is also a very important criterion for 5G, the FBMC schemes have, in general, better robustness against the Doppler effect due to the subcarrier filtering process. On the other hand, the UFMC scheme handle the Doppler effect in the same manner as CP-OFDM, the claimed advantage is that the subcarrier spacing can be made wider for a particular sub-band in order to serve high-mobility users.

4.6 The Latency

Latency is another important consideration for 5G networks, CP-OFDM is advantageous because of its short transceiver latency, which is mainly due to the FFT transform and CP, in other words $T+T_{CP}$. Any additional filtering will naturally increase the latency. Moreover, latency and spectrum confinement are two competing factors. FBMC has the highest latency, UFMC trades CP with the filtering transition period, which makes UFMC have the same latency as CP-OFDM.

4.7 The Complexity

One important advantage of the CP-OFDM is its low modem complexity. It is obvious that when working on some new advanced modulation simplicity might need to be sacrificed. It is important to compare the new candidates to CP-OFDM. In the FBMC scheme, the complexity is more than double. Regarding the UFMC, a direct implementation will lead to significant complexity increases, mainly due to the fact that the modulation of each resource block will consume one FFT transform. Thus, in an LTE setting where 100 resource blocks are to be modulated, the additional complexity will easily reach a factor of hundreds. According to a recent report, a frequency-domain realization can remarkably reduce modulation complexity, by a factor of 30. The reported modulation complexity increase in comparison with the CP-OFDM modulation is a factor of 8–10 for downlink on the base-station side, and the demodulation complexity is slightly more than doubled in comparison to CP-OFDM demodulation.

4.8 The Compatibility with 4G

Another consideration, but it does not mean that the new receiver is able to decode LTE signals; it rather means that the new system should preferably be able to reuse existing LTE techniques, like reference signal (RS) design and MIMO coding, in a straightforward manner. However, for FBMC systems, only real-valued symbols are transmitted due to offset QAM signalling. It thus cannot directly reuse the LTE techniques. For the UFMC scheme, it is claimed that the signal within the sub-band has the same character as the OFDM signal, the system can maintain a good compatibility with LTE.

5. Simulation Results and Analysis

A key performance index to evaluate the capacity-approaching is the BER given a received SNR over an

AWGN channel. We consider the following parameters (most used in the literature):

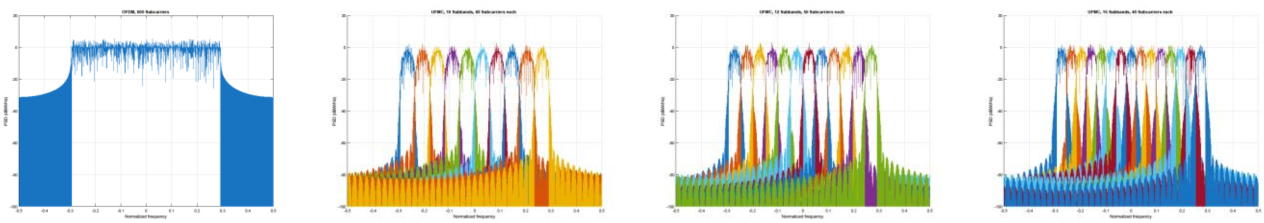
Table 1. Simulation Parameters

Overall Parameters		
FFT size	N_{FFT}	1024
Bit Per Symbol	m	2, 4, 6, 8
Resource block size	N_{sc}	12, 16
Number of active RBs	N_{RB}	50, 60
CP-OFDM Parameters		
Cyclic Prefix	N_{CP}	72 samples
UFMC Parameters		
Filter Length	$L=N_{CP}+1$	73
Stop band attenuation		40 dB
FBMC Parameters		
Overlapping Factor	K	2, 3, 4

In this section, we examine the performance of the FBMC and UFMC waveforms and compare the results with that of CP-OFDM. Our simulations have been carried out with parameters that are shown in Table 1. Monte Carlo simulation by MatLab is used to obtain the results shown in the following figures. For the evaluation, three performance metrics are considered the Power Spectral Density, the Probability of Error, and the Peak to Average Power Ratio. We can predict before simulations that in the first two metrics we will obtain some gain but in the PAPR metric the CP-OFDM will be better because of the filtering in both FBMC and UFMC which improves PAPR with respect to FBMC to became slightly worse than CP-OFDM.

5.1 Power Spectral Density – PSD

A comparison of the theoretical power spectrum density of CP-OFDM and UFMC for two different values of Resource blocks (NRB) and Number of subcarriers in each RB (NSC) is shown in Figure 5, where the PSD is represented in dBW/Hz and function of the normalized frequency. We can simply remark here two things, the first one the reduction of PSD in the Out of Band (OOB) region due to the filtering process used in UFMC, this reduction makes this new waveform more robust to the Inter-Carrier Interference, and the effect of the sub-band filtering which divided the overall PSD into a summation of sub-band PSDs.



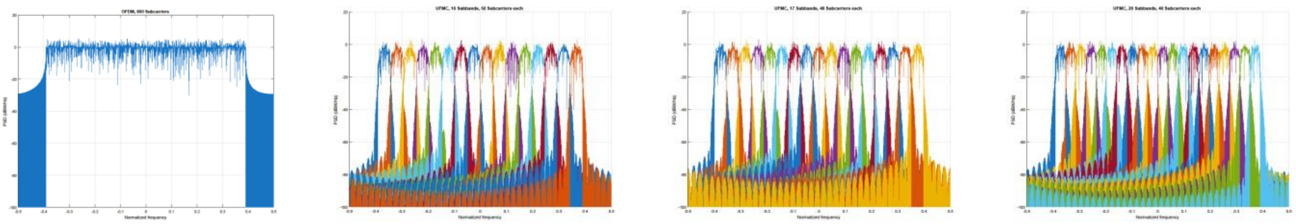


Figure 5. PSD Comparison between CP-OFDM and UFMC.

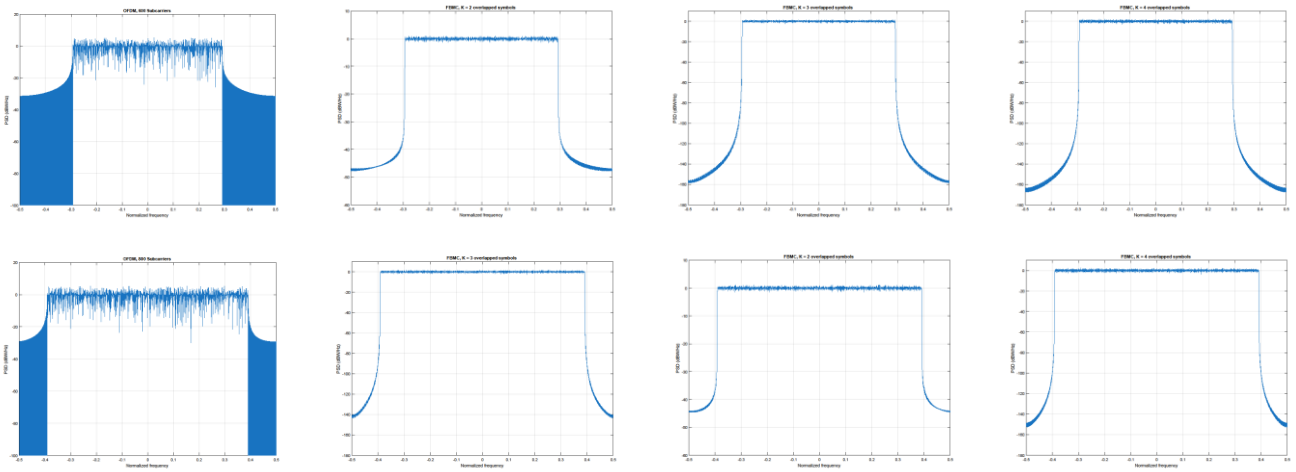


Figure 6. PSD Comparison between CP-OFDM and FBMC.

In Figure 6 the comparison of PSD between CP-OFDM with FBMC for various values of overlapping factor K is shown. Here, it is obviously shown that in FBMC the power in the OOB is very small compared to the power in the corresponding band. So, we can say that the FBMC has the best PSD when compared to the CP-OFDM and UFMC.

5.2 Bit Error Rate – BER

A comparison of the probability of error, which is presented by the BER, of UFMC and FBMC with respect to the different modulation levels from QPSK to 256QAM modulation is presented in Figure 7. This figure demonstrates what it was proved theoretically that when the modulation level increase the BER increase also.

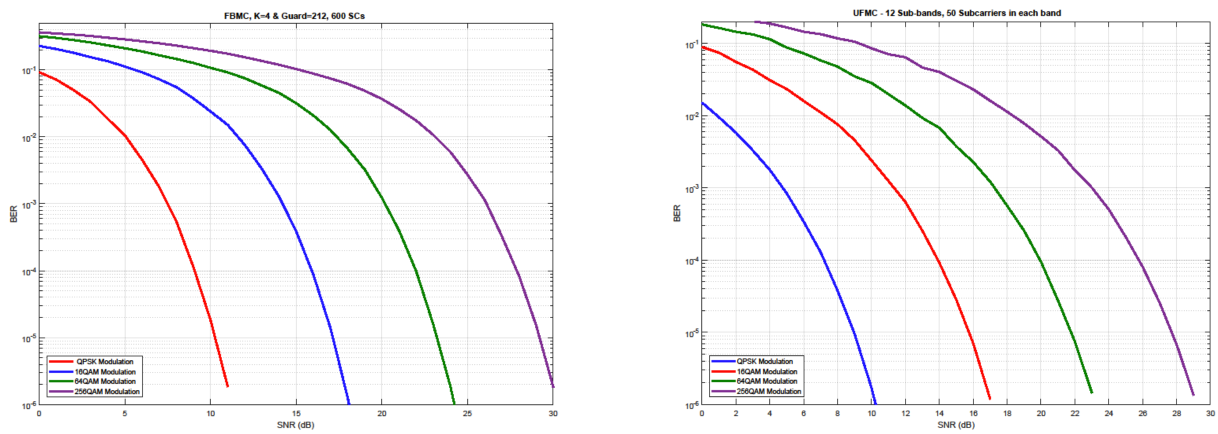


Figure 7. UFMC and FBMC performances with respect to modulation levels.

When compared to the CP-OFDM system the UFMC presents a net gain in all cases simulated in our work. Figure 8 shows that the UFMC using QPSK and different number of subcarriers has better BER from the CP-OFDM with approximately 2.5 dB at BER=10^{-5}. In the figure, the comparison between FBMC and CP-OFDM for QPSK modulation is presented. The simulation results show that the CP-OFDM and the FBMC waveforms have the same performance with respect to the BER whatever is the modulation or the number of subcarriers. So, we can say that UFMC has the best BER when compared to the CP-OFDM and FBMC.

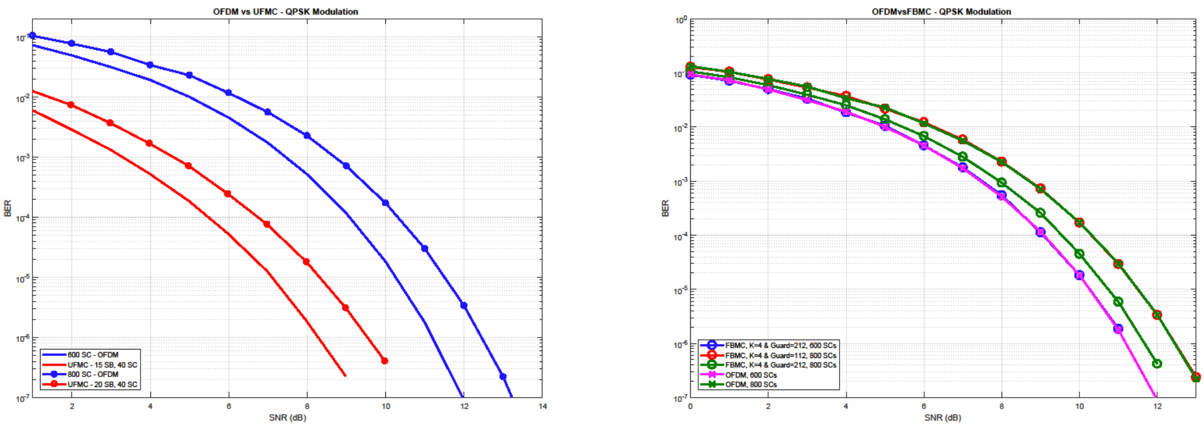


Figure 8. The comparison UFMC and FBMC vs CP-OFDM.

5.3 Peak-to-Average Power Ratio – PAPR

Theoretically, A CP provides a more constant amplitude, which reduces the peak to average power ratio (PAPR) and makes it appealing for power amplifiers. Furthermore, the CP allows for slightly smaller receive FFT sizes and potentially better coexistence with CP-OFDM.

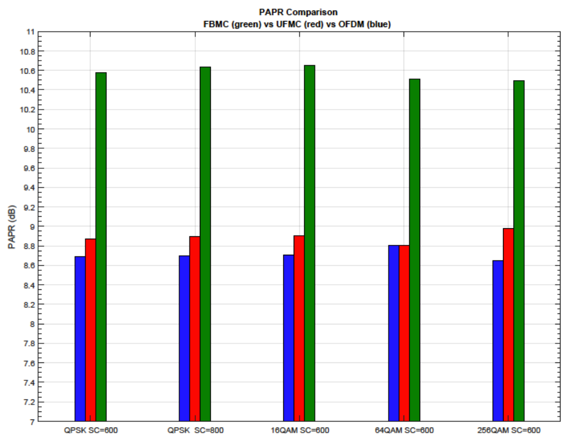


Figure 9. PAPR comparison between CP-OFDM, UFMC, and FBMC.

In the same time the filtering process increase the PAPR problem. So, we can expect that CP-OFDM will has the best PAPR ratio when comparing to the UFMC and FBMC, moreover, FBMC will have the worst

PAPR ratio since it uses the filtering process and does not add a cyclic prefix to the symbols. The Figure 9 confirms our theoretical conclusion, where the PAPR ratio is presented in dB for different modulations used and different number of subcarriers. In all these cases the PAPR of CP-OFDM is between 8.4 and 8.8 dB where the PAPR of UFMC is slightly worse to be between 8.8 and 9 dB and the PAPR of FBMC is larger than 10 dB. We can remark also that the difference between UFMC and FBMC varies but the one for UFMC is always near the one of CP-OFDM. So, when we use any waveform different that the CP-OFDM, we will lose in the PAPR, but with the UFMC the difference is not consequent.

6. Conclusion

In this paper, the implementation of two different candidates for the fifth generation, Universal-Filtered Multi-Carrier (UFMC) and Filter Bank Multi-Carrier (FBMC), is studied and presented. The first objective was to compare them with the conventional CP-OFDM but during our work, we have been capable to compare them between themselves. The simulation results show that each of the waveforms presented in this paper improves some parameters and deteriorates other parameters, so we need to take other criteria to choose the waveform for the next generation, like the tail issue, the complexity, the latency, and others. The FBMC and UFMC improve the PSD but deteriorate the PAPR ratio, in despite that UFMC has a PAPR ratio near to the one of CP-OFDM, in the same time the UFMC improve the BER rate, which push us to say that the UFMC represents a good candidate to the 5G system with respect to other metrics presented in this paper.

7. References

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