Performance Analysis of the Universal Filtered Multi-Carrier (UFMC) Waveform for 5G System

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Abstract. In the 5th generation mobile communication (5G) system, it is required to provide three different types of services, including enhanced Mobile Broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low-latency communication (URLLC). To meet all those demand in 5G, the waveform is crucial. Although the CP-OFDM waveform has been wildly used in 4G, it is hardly to satisfy the requirements of 5G. A lot of candidate waveforms are discussed for 5G system, including UFMC, FBMC, F-OFDM etc. In this paper, the UFMC waveform is discussed, the different filters and different frequency width of the subband in UFMC system are studied and appropriate parameters for the system are recommended.

1. Introduction

5G mobile communication system has drawn more and more attention recently. In 5G system, it is required to provide three different types of services, including enhanced MBB (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low-latency communication (URLLC). As predicted by METIS (The Mobile and Wireless Communication Enabler for the Twenty-twenty Information Society), 5G is multi-rate system, covering the user’s communication and machine type communication. Compared to 4G system, the Quality of Experience (QoE) of 5G system is fully improved, including 1000 times capacity, 10-100 times typical user’s data rate (upto 20 Gb/s), support 10-100 times connections (the number of serviced devices up to 1 million per square kilometre), 10 times battery life and 1/5 E2E delay (network latency up to 1 ms) compared to the 4G network [1-3].

The Cyclic Prefix OFDM (CP-OFDM) waveform is widely used in the 4G system, such as the LTE / LTE-Advanced and IEEE 802.11 series standard. It can achieve high spectral efficiency by closely spaced orthogonal sub-carrier signals. However, the performance that CP-OFDM provides in those 4G networks are not enough to support the diverse application in 5G networks. Since in frequency domain, the out-of-band (OOB) leakage of CP-OFDM is relatively high and in time domain, the use of cyclic prefix (CP) reduces the spectral efficiency. Moreover, the high Peak to Average Power Ratio (PAPR) of CP-OFDM lowers the performance of the system.

Therefore, new waveforms with new features, such as Universal Filtered Multi-Carrier (UFMC), Filter Bank Multicarrier(FBMC) and f-OFDM etc., are studied and proposed to be the candidate waveform for the coming 5G system.

The waveform FBMC is proposed and studied in [4, 5], in which the signal on each subcarrier is filtered and the effect of Inter Carrier Interference (ICI) is significantly reduced. However, the offset quadrature amplitude modulation (OQAM) modulation must be used, and that makes the FBMC...
system does not support MIMO transmission. On the other hand, the use of long length filter in FBMC waveform causes the system not fitting for short data transmission of machine type communication. Unfortunately, the machine-to-machine (M2M) communications is one of the most important application in 5G, and it involves exchanging of very short messages with a very short latency.

F-OFDM system filters the whole transmission band with a single filter, the OOB of the waveform is reduced compared to the CP-OFDM and filter length is greatly reduced compared to the FBMC [6, 7]. In universal filtered multicarrier (UFMC) systems, the subcarriers are grouped into subbands; each subband is filtered by a filter; Different filters can be applied for each subband to reduce the out-of-band spectral emissions.

Compared to FBMC system, the filter length in UFMC system is greatly reduced as the width of a subband is much wider than that of a single subcarrier in FBMC [8-13]. Moreover, unlike the FBMC, UFMC retains the complex orthogonality, it can still use QAM constellation and is compatible with the existing MIMO schemes.

Either FBMC or f-OFDM is a specific form of UFMC. In UFMC, each subband includes several subcarriers. In f-OFDM, there is only one subband covering the entire band. In FBMC, a subband includes only one subcarrier and the number of subband is the same as the number of subcarrier. The number of subbands in FBMC is maximum, and the number of subbands in f-OFDM is minimum: only one. In UFMC system, it is easy to adjust the width of the subband and the length of the filter to support the requirements of specific users. That makes the UFMC to be one of the most promising candidate waveforms for 5G systems.

This paper mainly discusses the performance of UFMC. Simulations with different parameters for UFMC system are made and the OOB and bit error rate (BER) performance are compared to that of CP-OFDM and FBMC system.

The rest of this paper is organized as follows: Section II describes the UFMC system model. In section III the filter with different side lob attenuation in UFMC System is studied. In section IV, the width of subband in UFMC system is studied and moderate scheme is proposed. Conclusions are made in section V.

2. System Model
Assume that there are \( N \) subcarriers in the UFMC system; all the subcarriers are divided into \( B \) subbands. The \( S_b \) \((b = 1, 2, \ldots, B)\) is the modulated QAM symbols in the \( b \) th subband, which including \( K_b \) subcarriers \((\sum_{b=1}^{B} K_b = N)\). The modulated symbols \( S_b \) \((b = 1, 2, \ldots, B)\) in each subband are send to the \( N \) point DFT module and then the filter module, the filtered signals from each subband are accumulated to be \( X \). The transmit signal in the UFMC can then be expressed as formula (1).

\[
X_{\text{UFMC}} = \sum_{b=1}^{B} \text{IDFT}(S_b)^* f_b
\]  

(1)

Where \( f_b \) is the coefficient of the filter for the subband \( b \). The system model of UFMC system is shown in figure 1 and the subbands in UFMC are shown in figure 2.
3. Filter with different side lobe attenuation in UFMC System

In UFMC system, the filter for each subband is very important. It can greatly reduce the OOB and improve the system performance. Assume that there are 512 subcarriers in the UFMC system and CP-OFDM system, among which 320 subcarriers are used for data transmission. The 320 data subcarriers are grouped into 8 subbands, each subband includes 40 subcarriers. Figure 3 and figure 4 are the normalized spectrum of the UFMC system and the CP-OFDM system. The OOB of the UFMC system is far less than the OOB of the CP-OFDM system because of the use of filter. The power spectral density(PSD) of the out-of-band signal reduces rapidly to -60dB in the UFMC system, while in the CP-OFDM system, the power spectral density(PSD) of the out-of-band signal only reduces to -20dB. That fully displays the advantage of the UFMC system.
The stopband attenuation of the subband filter is a key parameter for the system, the larger stopband attenuation, the less OOB of the signal, and that means the better system performance. Meanwhile, the large stopband attenuation needs steep spectrum performance, which results in long length filter and high complexity of the system. Therefore, to select appropriate stopband attenuation and filter length is the only method to balance the performance and the complexity of the system. In order to analyze the influence of the stopband attenuation to the system, simulations are made in this paper; the Chebyshev filter is assumed to be used in the simulation.

Figure 4 is the power spectral density (PSD) of the UFMC system

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Figure 5 is the bit error rate performance of the UFMC system with 4 QAM constellation used; figure 6 is the bit error rate performance of the UFMC system with 16 QAM constellation used.

It is obviously that as the side lob attenuation increasing, the system performance increases. When the side lob attenuation is 40dB, the system performance is the best and when the side lob attenuation is 5dB, the system performance is not so good. Considering the complexity of the system, 10dB or 20dB side lob attenuation is preferred since it can get good performance with relatively low complexity.

![Graph showing the power spectral density of UFMC, 8 Subbands, 40 Subcarriers each](image)

**Figure 4.** The power spectral density (PSD) of the UFMC system

![Graph showing the bit error rate performance of UFMC system with 4 QAM](image)

**Figure 5.** Bit error rate performance of the UFMC system (4 QAM)
Figure 6. Bit error rate performance of the UFMC system (16 QAM)

4. Width of subband in UFMC system

In UFMC system, the adoption of the subband greatly reduces the number of filter and the complexity of the filter. However, the width of the subband is the factor that affect the system performance and should be seriously designed.

Assume that there are 512 subcarriers in UFMC system, among which 480 subcarriers are used for data transmission. The 480 data subcarriers are divided into different subband with 4 schemes that are shown in table 1. Simulations are made with 4 QAM and 16 QAM constellation in the Gaussian channel and numerical results are shown in figure 7 and figure 8.

Table 1. Different scheme of the Subband

| Scheme   | Number of subband | Number of subcarriers in a subband |
|----------|-------------------|-------------------------------------|
| Scheme 1 | 24                | 20                                  |
| Scheme 2 | 48                | 10                                  |
| Scheme 3 | 80                | 6                                   |
| Scheme 4 | 240               | 2                                   |

In figure 7, 4QAM constellation is used, the performance of scheme 1 is not as good as other 3 scheme. When the bit error rate is $10^{-3}$, the scheme 1 is with 2dB performance degradation compare to scheme 2 and scheme 3. The scheme 4 is the best with the same parameters in the simulation and has no error bit when the SNR is 10 dB.
When 16 QAM constellation is used, the scheme 4 with the least width of the subband has the best performance too as is shown in figure 8, and the scheme 1 with the largest width of the subband has the worst performance. Therefore, the more subband and the fewer subcarriers in a subband, the better is the performance. As the complexity is considered, the moderate scheme such as scheme 2 and scheme 3 are recommended, and the real fading channel is another important factor that affect the selection of the scheme.

![Figure 7. Bit error rate performance(4 QAM)](image7.png)

![Figure 8. Bit error rate performance (16 QAM)](image8.png)

5. Conclusions
In this paper, the candidate waveform UFMC for 5G is studied. As the filter in the UFMC system is very important to reduce the OOB of the system, the side lob attenuation of the filter is studied. Simulation results show that the system performance increases as the side lob attenuation increasing, and 10dB or 20dB side lob attenuation is preferred considering the complexity of the system.
The performance of the UFMC system with different width of subband and different modulation constellation is also studied in this paper. The simulation results show that the more subbands and subband filters in the UFMC system, the better the system performance. That means subcarriers in the system should be divided into more subbands. As the complexity is considered, the moderate schemes are recommended.

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