WF-OFDM (Windowing and Filtering OFDM) System for the 5G New Radio Waveform

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Abstract - **The 2 approaches for the 5G new radio waveform design are the filtering and windowing for the spectrum efficiency improvement by reducing the OOB(out-of-band) power spectrum. As filtering method, UFMC (universal filtered multicarrier), FBMC (filter bank multi-carrier) and f-OFDM (filtered orthogonal frequency division multiplexing) waveforms are the potential candidates for a new waveform for 5G system. Another possible approach is to use the windowing in the conventional CP-OFDM system in order to reduce the OOB power spectrum. W-OFDM (window orthogonal frequency division multiplexing) is typical and show comparable performance. Each approach has some advantages and disadvantages together. The best OOB reduction performance can be shown in FBMC system. However, FBMC system is the most complicated and cannot support the general M-QAM (M-ary quadrature amplitude modulation) format. So, it is very important to design a novel OFDM-based waveform that has the similar OOB power spectrum to the FBMC and support the general M-QAM modulation as well. In this paper, we like to propose a WF-OFDM System for the 5G and 5G beyond mobile system waveform design. This WF-OFDM system uses a combination method of the filtering and windowing to get the synergy effect, so that the spectrum efficiency may be increased by reducing the OOB (out-of-band) power spectrum. 4 kinds of WF-OFDM systems are devised depending on the filtering and windowing positions for the OOB performance improvement. Simulations results show that the proposed WF-OFDM system has comparable or better OOB spectrum reduction characteristics to FBMC system. Especially, the proposed system WF-OFDM # 3 and #4 show the remarkable OOB reduction performance even in the short window length of 6 or 8.**

Keywords—waveform; new radio;WF-OFDM; filtering; windowing

I. Introduction

Conventional orthogonal frequency division multiplexing (OFDM) uses a wide guard band in order to avoid ACI. It decreases spectral efficiency when a number of mobile devices simultaneously access a base station [1-5]. Next generation mobile communication system requires high-level key performance indicators (KPIs). It is difficult for OFDM to satisfy the KPIs. Universal filtered multi-carrier (UFMC) and filter bank based multi-carrier (FBMC) are known as the candidate waveform for 5G mobile communication. f-OFDM is very similar to the UFMC system. These systems use filtering technique based on multi-carrier. These techniques have characteristic of low OOB power in comparison with conventional OFDM [8-9]. The best OOB reduction performance can be shown in FBMC system. However, FBMC system is the most complicated and cannot support the general M-QAM format. So, it is very important to design a novel OFDM-based waveform that has the similar OOB power spectrum to the FBMC and support the general M-QAM modulation.

In this paper, we like to propose a WF-OFDM (windowing and filtering - orthogonal frequency division multiplexing) system. The WF-OFDM system uses a combination method of the filtering and windowing to get the synergy effect, so that the spectrum efficiency may be increased by reducing the OOB (out-of-band) power spectrum. 4 kinds of WF-OFDM systems are devised depending on the filtering and windowing positions for the OOB performance improvement. They have the names of WF-OFDM #1, #2, #3, and #4. In the first proposed WF-OFDM #1, several divided subbands are filtered in each subband and windowed on the CP (cyclic prefix) part after these several divided subbands are summed. The second proposed WF-OFDM #2 is very similar to the first proposed WF-OFDM #1. However, several divided subbands are filtered in each subband and windowed after these several divided subbands are summed. Proposed system model WF-OFDM #1 and WF-OFDM #2 have the first filtering process and next windowing process. However, system model WF-OFDM #3 and WF-OFDM #4 have the first windowing process and next filtering process. These are very new proposed systems. The system model WF-OFDM #3 has each filtering process on each subband and summed into one OFDM symbol, but system model WF-OFDM #4 has only one filtering process after summing into one OFDM symbol.

Via the simulation results, it is confirmed that the proposed WF-OFDM system has comparable or better OOB spectrum reduction characteristics to FBMC system. Especially, the proposed system WF-OFDM # 3 and #4 show the remarkable OOB reduction performance even in the short window length of 6 or 8.

Finally, we can get the desirable OOB spectrum characteristics that are very important to save the frequency resources and can be useful for the next generation mobile system waveform. Conclusively, it can be confirmed that the suggested waveforms using the 4 kinds of combination method of the filtering and windowing to get the synergy effect is possible approach for the easily controlling and managing the waveform design to the variable requirements in some scalable applications of the future.

II. Conventional System Model

A. OFDM

OFDM system has advantages of orthogonality between each of subcarriers and robustness against ISI effect by CP. That is, OFDM system requires simple equalizer with one tap

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[12]. However, each subcarrier of OFDM system has high side-lobe power. As a result, channel capacity is decreased in OFDM system [12]. These drawbacks should be overcome for 5G mobile communication.

B. UFMC

UFMC system uses orthogonal multi-carrier, like OFDM system. UFMC filters each sub-band that consists of orthogonal multi-carrier in order to reduce OOB power [6]. The received signal is transformed into baseband signal by RF chain. Baseband signal is converted into digital signal by ADC. And then, time-domain pre-processing is processed. After the process, the series data stream is transformed into a parallel data stream by S/P. The time-domain parallel data stream is converted to frequency-domain stream by 2N-FFT operation [6]. After 2N-FFT operation, odd-numbered data symbols are selected and equalized. Spectrum of UFMC system has lower OOB power in comparison with spectrum of OFDM system. This is good advantage. However, because UFMC system uses multi-carriers and multi-carriers are overlapped, UFMC system has high PAPR. High PAPR characteristic can distort signal of UFMC system [6].

C. FBMC

In the transmitter of FBMC system, data symbols are transformed into parallel stream from series stream by S/P. The parallel symbols are modulated to offset quadrature amplitude modulation (OQAM) signal [7]. The modulated OQAM signal is transformed into a signal filtered by each sub-carrier by using the synthesis filter bank that consists of IFFT and poly phase network (PPN) [7]. Finally, the amplified FBMC signal is transmitted by antenna. Receiver of FBMC system consists of reversed structure in comparison with FBMC transmitter. FBMC system has lower OOB power in comparison with UFMC system and OFDM system. This is a good advantage. However, FBMC system has high system complexity. Because FBMC system uses multi-carrier, it has high PAPR.

D. W-OFDM

W-OFDM is an improved version of OFDM system. Fig.1 shows the W-OFDM system. W-OFDM system does not use the filter but it uses the extension and windowing method on each OFDM symbol in order to reduce OOB power of spectrum.

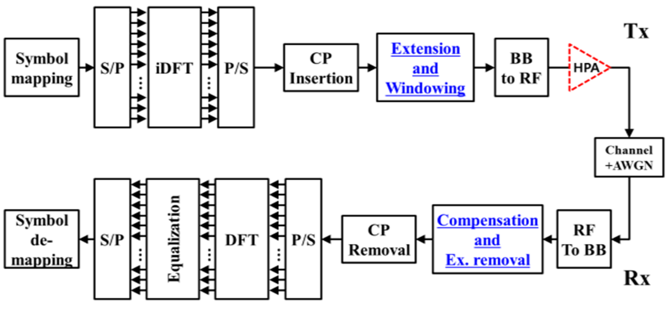

Fig. 1. Block diagram of W-OFDM system.

III. PROPOSED WF-OFDM SYSTEMS

In this paper, we like to propose several kinds of WF-OFDM system for the 5G and beyond 5G mobile communication system waveform design. The WF-OFDM system uses a combination method of the filtering and windowing to get the synergy effect, so that the spectrum efficiency may be increased by reducing the OOB (out-of-band) power spectrum.

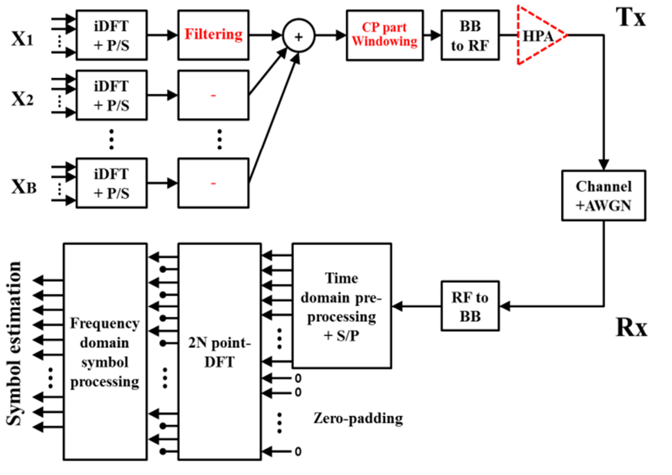

Fig.2. Proposed system model 1 - WF-OFDM #1.

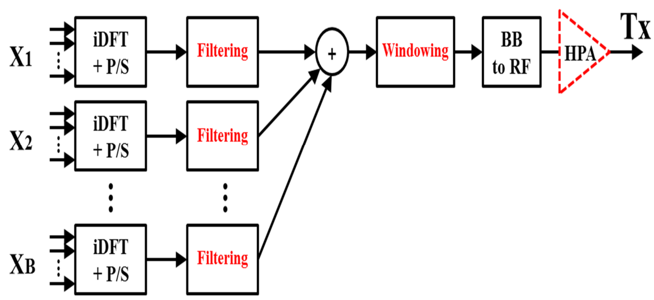

Fig.3 Proposed system model 2 - WF-OFDM #2.

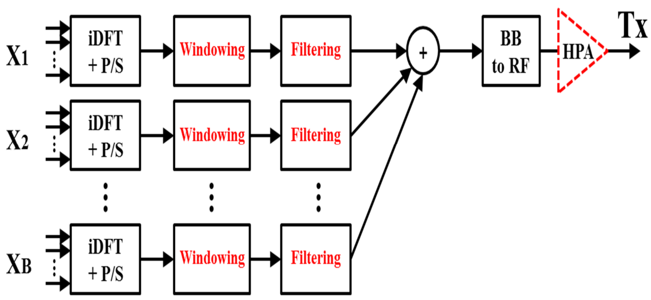

Fig.4 Proposed system model 3 - WF-OFDM #3

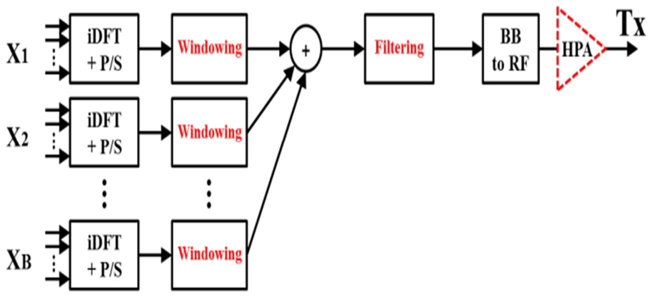

Fig.5. Proposed system model 4 - WF-OFDM #4

Fig.2, 3, 4, and 5 are the proposed 4 kinds of WF-OFDM system. 4 kinds of combination systems are devised depending on the filtering and windowing positions for the OOB performance improvement. We like to get the desirable OOB spectrum characteristics that are very important to save the frequency resources and can be useful for the next generation mobile system waveform. They can be designed by some modification from the conventional OFDM system. The suggested waveforms using the 4 kinds of combination method of the filtering and windowing to get the synergy effect is possible approach for the easily controlling and managing the waveform design to the variable requirements in some scalable applications of the future.

Fig.2 shows the proposed system model 1 - WF-OFDM #1. As in Fig.2, several divided subbands are filtered in each subband and windowed on the CP (cyclic prefix) part after these several divided subbands are summed. Several subbands filtering method is almost same to the f-OFDM system. But the second additional windowing process is added to get sharper OOB spectrum.

Fig.3 shows the proposed system model 2 - WF-OFDM #2. This is very similar to the proposed system model 1 - WF-OFDM #1.However, As in Fig.3, several divided subbands are filtered in each subband and windowed after these several divided subbands are summed. Several subbands filtering method is almost same to the UFMC system. But the second additional windowing process is added to get sharp OOB spectrum.

Fig. 4 and 5 are the proposed system model 3 - WF-OFDM #3 and system model 4 - WF-OFDM #4. Proposed system model WF-OFDM #1 and WF-OFDM #2 have the first filtering process and next windowing process. However, system model WF-OFDM #3 and WF-OFDM #4 have the first windowing process and next filtering process. These are the very new proposed systems. The system model WF-OFDM #3 has each filtering process on each subband and summed into one OFDM symbol, but system model WF-OFDM #4 has only one filtering process after summing into one OFDM symbol.

IV. Simulation Results and Analysis

In order to investigate the reduction of the OOB PSD (out-of-band power spectrum density) of each proposed system, we use the simulation parameters as in the follows. Also, Table 1 shows the OOB PSD comparison of the conventional OFDM, UFMC, FBMC and W-OFDM systems.

iFFT size for transmitter = 64
FFT size for receiver = 128
\# of sub-carrier in sub-band = 8
\# of used sub-band = 2
\# of used sub-carrier = 16
CP part window function_ Chebyshev windowing

Table 1. OOB comparison of conventional systems.

	OFDM	UFMC	FBMC	W-OFDM
OOB PSD	-26 dBc	-83 dBc	-130 dBc	-66 dBc

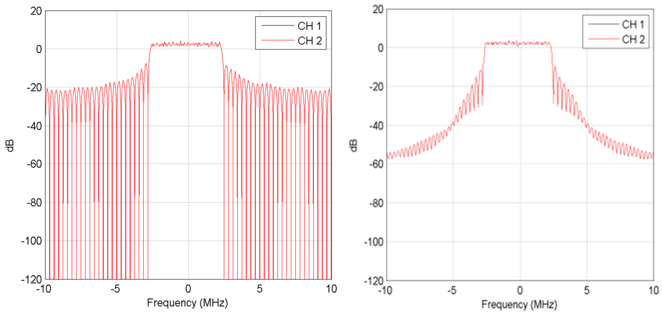

Fig.5. Power Spectrum of proposed system model 1 - WF-OFDM #1

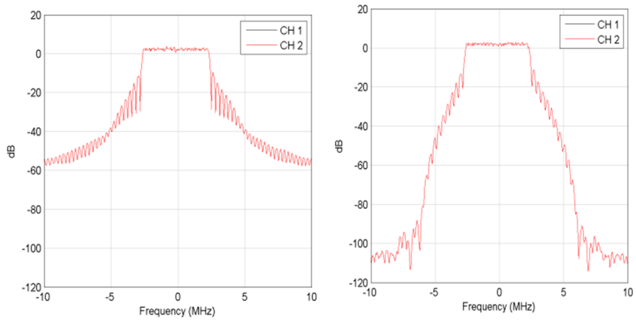

Fig.6. Power Spectrum of proposed system model 2 and 3 - WF-OFDM #2 and #3 (window length: left &right length = 4).

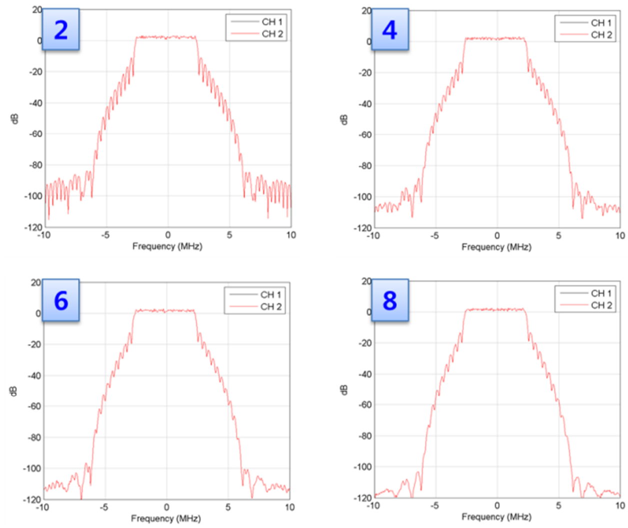

Fig.7. Power Spectrum of proposed system model 3 - WF-OFDM #3 (window length : left & right length =2, 4, 6, 8).

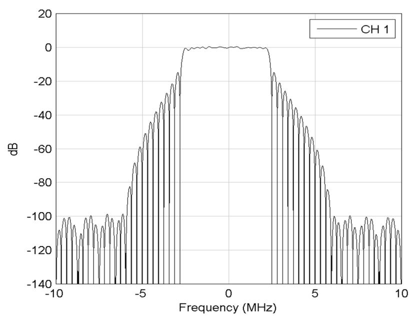

Fig.8. Power Spectrum of proposed system model 4 - WF-OFDM #4 (only filtering and without windowing)

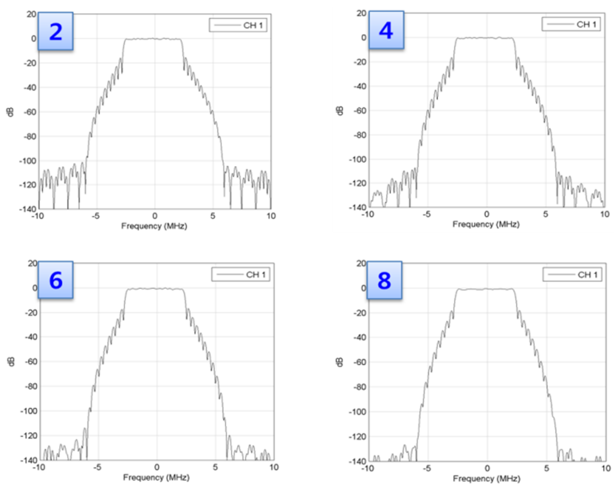

Fig.9. Power Spectrum of proposed system model 4 - WF-OFDM #4 (window length: left &right length =2, 4, 6, 8).

Table 2. OOB Comparison of the proposed WF-OFDM system.

Proposed WF-OFDM	WF-OFDM #1 (window length : 4)	WF-OFDM #2 (window length : 4)	WF-OFDM #3 (window length : 8)	WF-OFDM #4 (window length : 8)
OOB PSD	-22 dBc	-56 dBc	-132 dBc	-138 dBc

Simulations results show that the proposed WF-OFDM system has comparable or better OOB spectrum reduction characteristics to FBMC system. Especially, Fig. 7, 8 and9 of the proposed system WF-OFDM # 3 and #4 show the remarkable OOB reduction performance even in the short window length of 6 or 8. Moreover, the proposed WF-OFDM system can be designed by simple some modification from the conventional OFDM system. We can get the desirable OOB (out-of-band) spectrum characteristics that are very important to save the frequency resources and competitively similar shape to the OOB spectra of FBMC and UFMC system. OOB spectrum is very improved to the acceptable level

V. Conclusions

Until now, the best OOB reduction performance can be shown in FBMC among the many kinds of waveforms for 5G and beyond 5G mobile system. However, FBMC system is the most complicated and cannot support the general M-QAM (M-ary quadrature amplitude modulation) format. So, it is very important to design a novel OFDM-based waveform that has the similar OOB power spectrum to the FBMC and support the general M-QAM modulation. In this paper, we have proposed a WF-OFDM (windowing and filtering - orthogonal frequency division multiplexing) system for the 5G and 5G beyond mobile system waveform design. The WF-OFDM system uses a combination method of the filtering and windowing to get the synergy effect, so that the spectrum efficiency may be increased by reducing the OOB power spectrum. 4 kinds of combination systems are devised and investigated for the OOB performance improvement. Via the simulation results, it is confirmed that the proposed WF-OFDM system has comparable or better OOB spectrum reduction characteristics to FBMC system. Especially, the proposed system WF-OFDM # 3 and #4 show the remarkable OOB reduction performance even in the short window length of 6 or 8. Moreover, the proposed WF-OFDM system can be designed by simple some modification from the conventional OFDM.

Finally, we can get the desirable OOB spectrum characteristics that are very important to save the frequency resources and can be useful for the next generation mobile system waveform. They can be designed by some modification from the conventional OFDM system. Conclusively, it can be confirmed that the suggested waveforms using the 4 kinds of combination method of the filtering and windowing to get the synergy effect is possible approach for the easily controlling and managing the waveform design to the variable requirements in some scalable applications of the future.

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