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# UFMC and f-OFDM: Contender Waveforms of 5G Wireless Communication System

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***Abstract*—Because of the increased demand for high data rates, looking for using new technologies that meet these requirements are considered a necessary. Hence, Fifth Generation (5G) is expected to be impressive in offering these requirements and implement around 2020. Orthogonal Frequency Division Multiplexing (OFDM) is considered a main technology of LTE wireless communication standards. Due to its suffering from high Bit Error Rate (BER) and Peak Average Power Ratio (PAPR), OFDM doesn't consider as charming solution for future wireless communications and several emerging applications of 5G. Moreover, high Out of Band Emission (OOBE) and inability of supporting the flexible numerology are other demerits of OFDM systems. Thus, looking for alternative waveforms which have the ability of solving OFDM disadvantages are necessary to introduce it as contender candidate for 5G wireless communication systems. In this paper, both of Filtered-OFDM (f-OFDM) and Universal Filtered Multi carrier (UFMC) systems have been discussed for 5G wireless communication systems and compared to OFDM system. The results showed that f-OFDM system is better than both OFDM and UFMC systems and could be introducing as competitive candidate for 5G wireless communication systems because of its ability of reducing OOBE and enhancing BER performance.**

***Keywords—5G, f-OFDM, UFMC, OFDM, OOBE, PAPR***

## I. INTRODUCTION

Since 2010, fourth generation (4G) of cellular networks has been introduced under name Long Term Evolution (LTE). It is improved to be suitable for providing high data bandwidth for synchronized devices such as smartphones and tablets [1]. However, because of the increased demand for high data rates, looking to use new technologies that meet these requirements are considered a necessary. Hence, Fifth Generation (5G) is expected to be impressive in offering these requirements and implement around 2020 [2], [3]. Where, the applications that work on 5G communication system required a lower latency, high data rate and effective spectrum usage better than 4G communication systems [4], [5]. So, 5G communication systems are recently researched widely in order to support several sophisticated applications like Tactile internet, Internet of Things (IOT) and Gigabit wireless connectivity [5].

In General, Orthogonal Frequency Division Multiplexing (OFDM) is considered a main technology of LTE wireless communication standards [6] owing to its immunity Inter Symbol Interference (ISI) and multipath fading. However, it is suffering from high Bit Error Rate (BER) and Peak Average Power Ratio (PAPR) [7]. Moreover, high Out of Band Emission (OOBE) and inability of supporting the flexible numerology are other demits of OFDM systems. Where, the applications of 5G need to flexible numerology to be unpreceded prosperity as well as demand different waveform parameters like cyclic prefix (CP) length and subcarrier spacing. Due to these demerits, OFDM doesn't considered as charming solution for future wireless communications and several emerging applications of 5G [6].

Different studies were conducted to find an alternative waveform that have the ability of solving OFDM disadvantages and could be introducing as contender candidate for 5G wireless communication systems. Hence, Filtered-OFDM (f-OFDM) has been suggested as candidate solution to meet 5G requirements, it could provide great flexibility better than conventional CP-OFDM [6], [8]-[12]. It is similar to OFDM system with one difference is the use of filtering to minimize OOBE and achieve better spectral localization [8]. In other hand, the performance of OFDM and f-OFDM have been analyzed in Machine Type Communications (MTC). The signal to noise pulse interference ratio (SINR) is evaluated for both OFDM and f-OFDM in existence of interference. They showed that the results are improved by using f-OFDM through reducing undesirable distortion. The minimizing of the complexity in f-OFDM which are similar to OFDM and its ability of using spectral gaps efficiently make it one of the competitor for evolution of mobile communications air interface [13].

In contrast, Universal Filtered Multi carrier (UFMC) system is also considered one of the contender candidate waveform for 5G communication systems owing to its immunity against Inter Carrier Interference (ICI) and ISI as well as it appropriates for low latency scenarios [14]-[18]. Furthermore, UFMC is considered an alternative waveform can be overcoming of OFDM disadvantages and maintaining its advantages [16], [17]. It was compared with OFDM which is used in 4G networks and analysis the effectiveness of each of them [15]. They concluded that, by comparing with LTE-Advanced networks that utilizing OFDM, the spectral efficiency has been enhanced for future mobile communication networks by using UFMC in 5G networks. Where, the data transmission is increased by eliminate the CP in UFMC, while the side lobe level subcarrier is reduced owing to additional filtration. In additional to, UFMC outperforms of OFDM in terms of resistant to estimation errors of time and frequency shifts [15]. On the other hand, UFMC and Filter bank based multicarrier (FBMC) are reviewed and compared with OFDM in [19]. They showed that although FBMC is better than OFDM in theory, but it is suffering of many issues practically. So, UFMC could collect the merits of FBMC and avoid its demerits.

In this paper, the performances of f-OFDM, UFMC and OFDM systems have been discussed and compared in terms of OOBE, PAPR and BER to conclude which one is a good

contender candidate for 5G mobile communication system. The rest of the paper is organized as follows, the block diagrams of f-OFDM, UFMC and OFDM are explained in section 2. Whereas, section 3 is presenting the comparison results and discussion. Lastly, some conclusions have been pointed out in section 4.

## II. System Diagram

Block diagrams of each OFDM, UFMC and f-OFDM systems will be explained in this section. Where, system parameters that used in this paper are explained in table I. OFDM is particular used in 4G, it is a multicarrier modulation scheme as shown in figure 1. OFDM system has the ability of transmit a large number of digital data via a radio wave. In time domain, OFDM utilizes unpretentious square windowing pulse shaping which is resulting the sinc shape in frequency domain [20].

On the other hand, block diagram of f-OFDM system has been shown in figure 2. Where, novel f-OFDM system waveform enables coexistence and spectrum slicing of multi subbands. To minimizes the interference between neighboring subbands, f-OFDM system uses K band limited filters on the baseband OFDM signals. So, it could suppresses the interference and OOBE from the neighboring subbands to enough low level. To meet the requirements depending on the application scenario, the numerology for each subbands can be obtained in f-OFDM. To achieve trade-off between frequency and time localization, the used filter must be designed carefully. While, the FIR filter (windowed Sinc method) is usually utilized [21].

TABLE I. System Parameters

| **Transmission Bandwidth** | | **5MHz** |
|---|---|---|
| IFFT/FFT Points | | 512 |
| Occupied Subcarrier | | 300 |
| Cyclic Prefix Length | | 36 |
| Modulation | | 64QAM |
| Filter Design f-OFDM | Type | RRC Windowed-Sinc |
| | Roll-off factor (α) | 0.6 |
| | Length | 513 |
| UFMC | Sub band offset | 156 |
| | Filter length | 43 |
| | Side lobe attention | 40 |

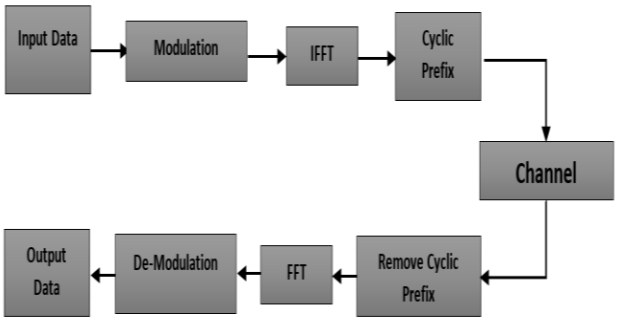


Fig. 1. OFDM transceiver.

Nowadays, UFMC modulation method is considered a highly research involved 5G. It works equivalent to the generality of FBMC and f-OFDM modulations. UFMC is performed by a group of subcarrier modulation unlike FBMC which is works by self-subcarrier modulation. Where, the grouping of subcarrier minimizes the filter length compared to FBMC as well minimizes the time of modulation perform. Both transmitter and receiver of UFMC are shown in figure 3. The Whole band will be dividing into subbands and it will be processing individually in UFMC, each subbands have a fixed number of sub-carriers [4].

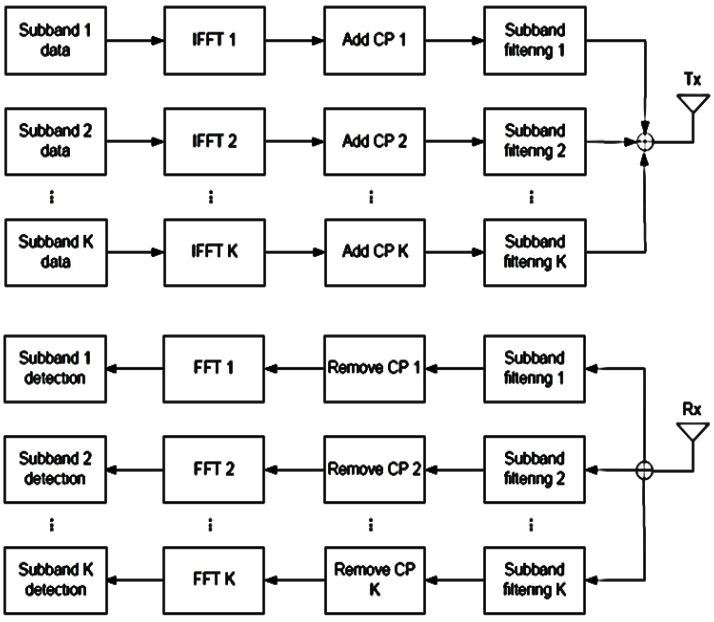


Fig. 2. Filtered OFDM system.

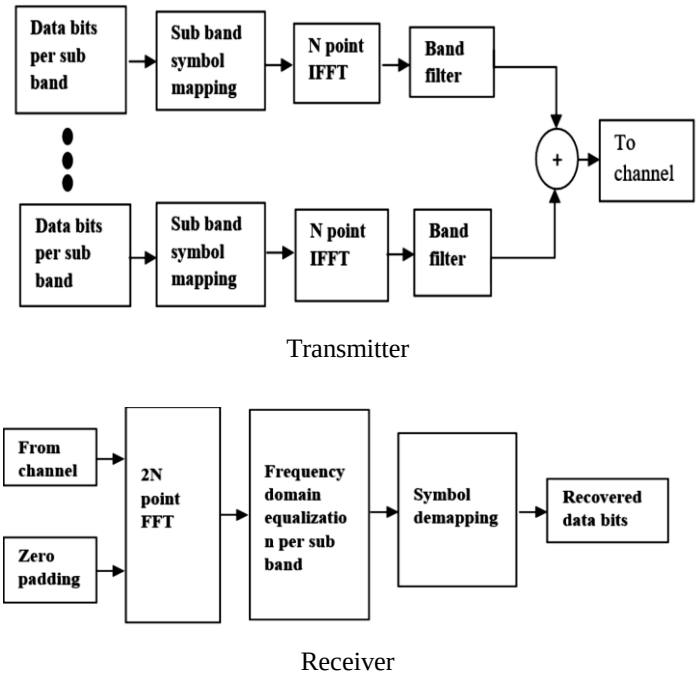


Fig. 3. UFMC system.

## III. Results and Discussion

In this section, three criteria's namely OOBE, PAPR and BER have been discussed for f-OFDM and UFMC systems and compared to OFDM. The aims of did this comparisons to show the best waveform that can be introducing for 5G wireless communication systems.

First, the Power Spectral Density (PSD) of 200 subcarriers for both OFDM and UFMC systems are depicted in figure 4 [4]. Where in UFMC, the whole band will be divided into 10 subbands, each one contents 20 subcarriers which less side lobes than OFDM. So, the OOBE level of UFMC is less than OFDM system as shown in figure 4.

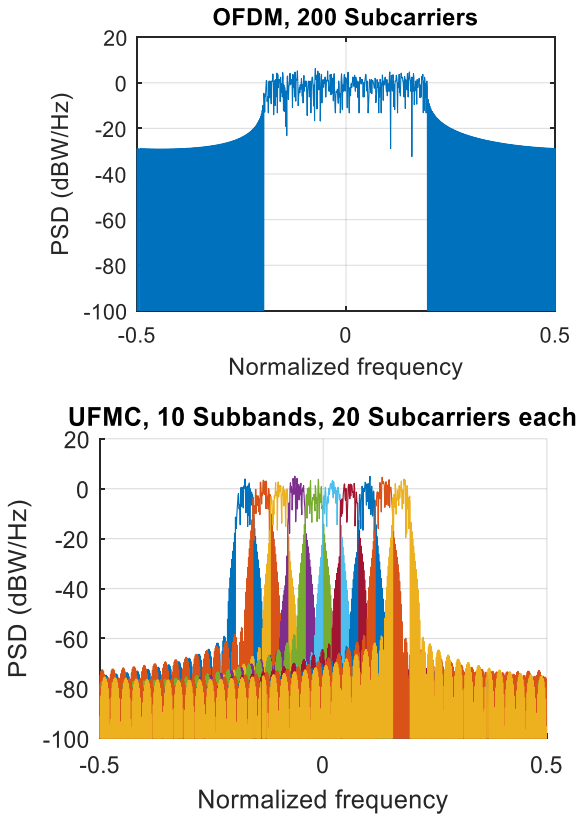


Fig. 4. PSD for UFMC versus OFDM systems.

Whilst, the comparison of PAPR for OFDM versus UFMC are presented in table II.

TABLE II. PAPR VALUES

| Technique | OFDM | UFMC |
|---|---|---|
| PAPR (dB) | 9.9269 | 8.6229 |

Table II showed that the PAPR value has been reduced in UFMC system compared to OFDM system, where it was 8.6229 dB in UFMC versus 9.9269 dB in OFDM. So, using UFMC system is contributing in minimizing the PAPR value better than conventional OFDM system

Figure 5 depicted the PSD for f-OFDM versus OFDM systems. It shows that the OOBE level of f-OFDM is also lower than OFDM system. So, OOBE levels of both UFMC and f-OFDM systems are lower and better than OFDM system. Whereas, the comparison of PAPR values between OFDM and f-OFDM systems are presented in table III.

Table III shows that the value of PAPR of f-OFDM was 11.5702 dB and 8.5584dB for OFDM. Thus, f-OFDM couldn't minimize the PAPR value lower than OFDM system unlike UFMC system which achieve lower value of PAPR than conventional OFDM system. Lastly, the comparison of BER performances among f-OFDM, UFMC and OFDM systems are depicted in figure 6.

TABLE III. PAPR VALUES

| Technique | OFDM | f-OFDM |
|---|---|---|
| PAPR (dB) | 8.5584 | 11.5702 |

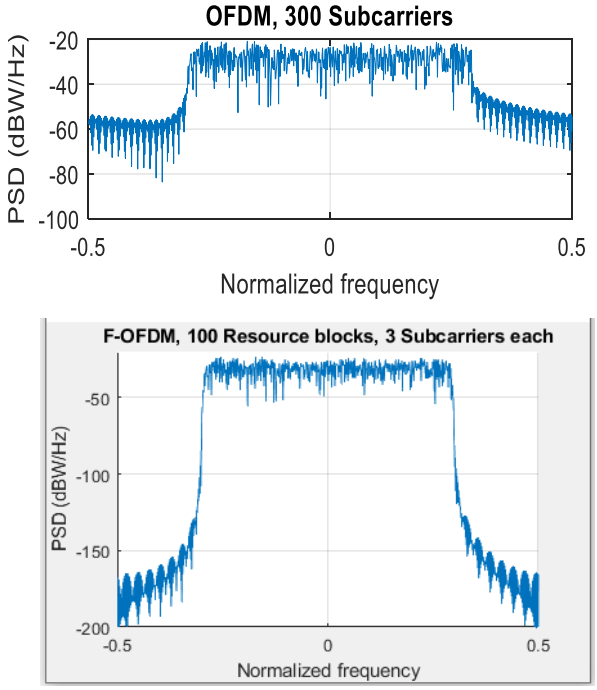


Fig. 5. OOBE of f-OFDM versus OFDM systems.

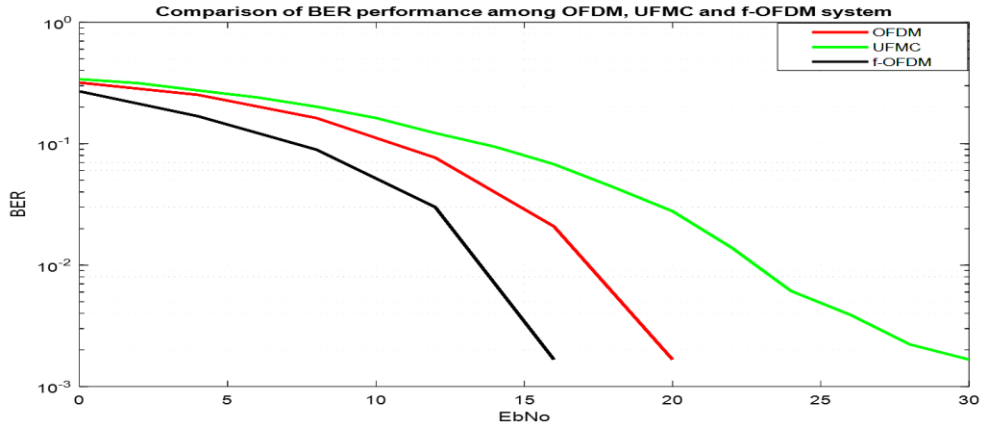


Fig. 6. OFDM, UFMC and f-OFDM system performance.

The results in figure 6 show that the BER performance for UFMC system was the worst, while it was the best for f-OFDM system for all values of SNR. So, the f-OFDM system performance is considered the best in between OFDM and UFMC systems.

All these results proved that both of UFMC and f-OFDM systems could reduce OOBE values better than OFDM system however, f-OFDM couldn't minimize PAPR value which may need to use other techniques to help it in reducing PAPR values unlike UFMC system that achieved lower PAPR value than OFDM system. In contrast, compared to UFMC and OFDM systems, BER performance of f-OFDM was the best, while UFMC system was the worst compared to f-OFDM and OFDM systems. So, could be considering the performance of f-OFDM system the best in between OFDM and UFMC systems and introducing as a contender candidate for 5G wireless communication systems, owing to the ability of reducing OOBE and improving BER performance better than both of them.

## IV. Conclusion

In this paper, both systems f-OFDM and UFMC have been discussed and compared to OFDM system to show which one is considered a promising contender for 5G wireless mobile communication systems. Where, because of the OFDM disadvantages such as high PAPR, OOBE and BER, it doesn't consider a charming solution for future wireless communications and several emerging applications of 5G. The results show that both of f-OFDM and UFMC able to reduce OOBE better than OFDM system. In contrast, UFMC system able to reduce PAPR value better than OFDM system where, it achieved 8.6229 dB versus 9.9269 dB for OFDM system. Unlike, f-OFDM system wasn't able to reduce PAPR value where, it achieved 11.5702 dB versus 8.5584 dB for OFDM. The BER performance of UFMC system was the worst compared to both OFDM and f-OFDM systems, while it was the best for f-OFDM system compared to OFDM and UFMC systems for all values of SNR. So, could be introducing the f-OFDM system as a contender candidate for 5G wireless communication systems, owing to the ability of reducing OOBE and improving BER performance better than both of OFDM and UFMC systems.

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