Chapter 36
Modulation Techniques for Next-Generation Wireless Communication-5G

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1 Introduction

Today is an era of wireless communication. In the last decade, significant amount of research has been done in the field of wireless communication. Wireless communication consists of radio frequency (RF) and optical wireless communication (OWC). OWC can be divided into visible light communication (VLC) and free space optics (FSO) [1]. In FSO, laser diodes are used and LED's are used for data transmission in VLC. Photodetector is used for reception of data for both FSO and VLC [2].

In the recent years, information and communication technologies have shown numerous growth and advancement. As the demand for communication quality is increasing, the requirement of high speed, high spectrum efficiency, and low latency communication networks is increasing. This increase in the demand can be fulfilled with the next-generation wireless communication technologies, i.e., 5G. In this paper, CP-OFDM, F-OFDM, FBMC, and UFMC as next-generation wireless communication technologies (NGWCT) are analyzed. CP-OFDM is already existing technology which suffers from inconsistencies like out of band distortion, poor frequency localization, and length of CP. These drawbacks can be overcome using filtered OFDM,

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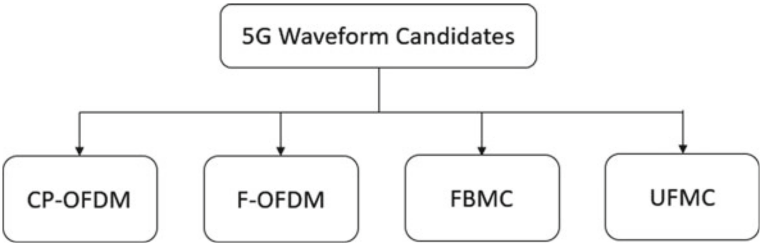

Fig. 1 5G waveform candidates

FBMC, and UFMC modulation technologies. The waveform design in 5G uses filter-based waveforms which can be categorized into three types: subcarrier, sub-band and full band filtering [3].

In Fig. 1, the different 5G waveform candidates are shown. The rest of paper is organized as follows: Sect. 2 discusses the performance analysis of 5G waveform candidates (CP-OFDM, F-OFDM, FBMC, UFMC), and conclusion is provided in Sect. 3.

2 5G Waveform Candidates

There has been a great interest of waveforms either it is previous generation or next-generation technologies. The candidate waveforms can be classified into single-carrier waveforms and multi-carrier waveforms. In this paper, only multi-carrier waveforms are analyzed.

(1) CP-OFDM

The cyclic prefix OFDM is the most deployed and researched multi-carrier technique in wired and wireless communication in last two decades. CP-OFDM offer advantages like orthogonality of subcarriers, adaptive modulation techniques, and low inter-symbol inter-reference (ISI) by using CP. The block diagram of OFDM is shown in Fig. 2.

The transmitted signal of CP-OFDM can be represented as

$$s(t) = \sum_{n=0}^{N-1} d_n e^{j2\pi k \frac{n}{N}} \tag{1}$$

where d_n is the complex data symbol and N is the total number of subcarriers [4].

The bit error rate of M-QAM technique is given by [5]

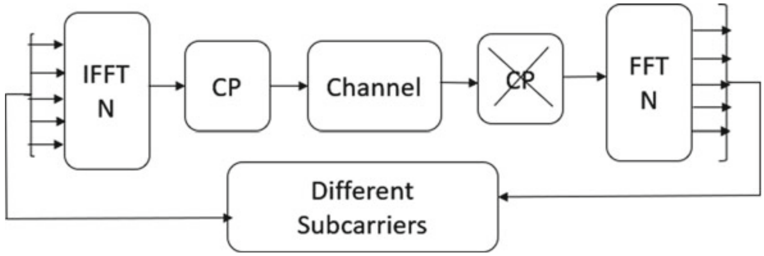

Fig. 2 Block diagram of OFDM

$$\mathrm{BER} = \frac{2}{\log_2(M)}\left(1 - \frac{1}{\sqrt{M}}\right)Q\left(\sqrt{\frac{\frac{3}{(M-1)}\log_2(M)E_b}{N_o}}\right) \tag{2}$$

where E_b/N_o is the signal-to-noise ratio and M is the constellation size.

In spite of several advantages, the CP-OFDM carries some drawbacks such as out of band distortion, length of cyclic prefix, and poor frequency localization [6, 7]. To overcome these drawbacks, filter-based multicarrier techniques are discussed below.

(2) F-OFDM

Filtered OFDM is based on full-band filtering principle. In this technique, only one pair of transmit and receive filters is required. The advantage of F-OFDM over CP-OFDM is reduced out of band distortion. Based on requirement of service and power, different modulation techniques can be employed in F-OFDM [8]. Asynchronous property of F-OFDM is one of its main advantage [9]. Filter length is the main weakness of F-OFDM. If the length of filter is larger than the (1/2 OFDM symbol), then there is a reduction in frequency spectrum. If the filter length is smaller than normal, then out of band distortion increases [10]. The block diagram of F-OFDM is shown in Fig. 3.

In Fig. 3, the different subcarriers are converted into time domain using inverse fast Fourier transform (IFFT). Addition of cyclic prefix is done before full-band filtering of time domain signal which is transmitted through wireless channel and matched filter is used at the receiver. The cyclic prefix is removed before FFT operation, and data is received. The F-OFDM transmitted signal can be represented as

$$s(t) = \sum_{l=0}^{L-1} s_l\big(n - l(N + N_g)\big) \tag{3}$$

where N_g is the CP length, $S_l(n)$ is the transmitted pulse, l is the subcarrier position, and L is the total number of symbols [11]. The BER of F-OFDM is same as OFDM. The next candidate for 5G is FBMC.

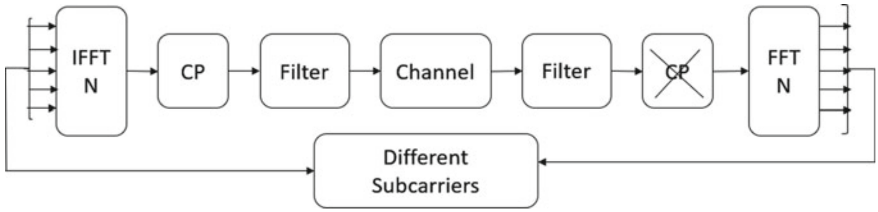

Fig. 3 Block diagram of F-OFDM

3 FBMC

The main principle of FBMC is subcarrier filtering. In this technique, the bandwidth is divided into subcarriers and per subcarrier filtering is done. As a result, the out of band distortion is reduced, and spectral efficiency is increased [12]. The block diagram of FBMC is shown in Fig. 4.

In Fig. 4, signal mapping is done to input data before offset quadrature amplitude modulation (OQAM) is done. Then, the signal is up sampled and filtered through prototype filter. After conversion into time domain, the signal is received at receiver passing through wireless channel. At the receiver, the signal is filtered, and demodulation is done before down-sampling. The main disadvantage of FBMC is that the tail of filter impulse response is longer than other filter-based 5G techniques which makes it not suitable for small packet transmission applications. Also, subcarrier filtering increases its computational complexity than OFDM [13]. The transmitted signal of FBMC can be represented as

$$s(t) = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} g_{l,k}(t) x_{l,k} \tag{4}$$

where $x_{l,k}$ is the transmitted signal, l is the subcarrier position, k is the time-position, and $g_{l,k}(t)$ is the transmitted pulse [14]. The next candidate for 5G is UFMC.

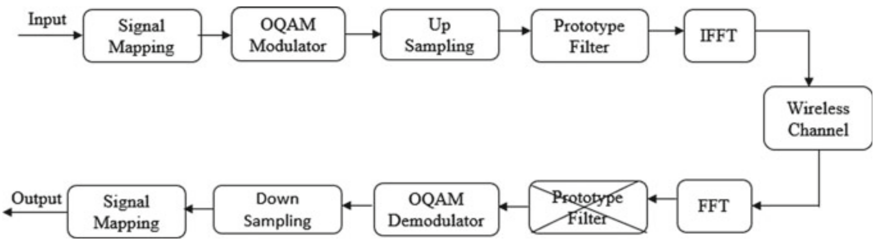

Fig. 4 Block diagram of FBMC

4 UFMC

FBMC works on the principle of sub-band filtering. In this technique, only transmit filter is used, and 2N-point FFT is used at the receiver. It uses suitably designed filters to overcome the drawbacks of F-OFDM and FBMC. The block diagram of UFMC is shown in Fig. 5.

In Fig. 5, the transmitter filter used is of type sub-band filtering, and output of all the filters is combined, and transmitter signal is generated. Zero padding is done at the received signal from wireless channel. 2N-point fast Fourier transform (FFT) is used before down-sampling the signal by a factor of 2. Main advantage of UFMC over FBMC is that it is suitable for short burst transmission and latency is reduced [15]. One of the limitations of UFMC is that inter-symbol interference which is introduced once the filter length is increased beyond the symbol duration [16]. The transmitted UFMC signal can be represented as

$$s(t) = \sum_{b=0}^{B-1} \sum_{l=0}^{L-1} \sum_{n=0}^{N-1} d_n^b g(l) \mathrm{e}^{j2\pi k \frac{(n-l)}{N}} \tag{5}$$

where B is the sub-band (blocks), L is the length of filter, d_n^b is the data on nth subcarrier, and bth sub-band, $g(l)$ represent finite impulse response (FIR) filter windowing function [4].

The comparison of 5G waveform candidates is given below. The power spectral density comparison of 5G candidates is shown in Fig. 6.

The analysis of Fig. 6 conclude that FBMC has the lowest OOB distortion among all the 5G techniques. UFMC and F-OFDM has almost similar PSD, and OFDM has largest OOB among all techniques. Computational complexity is an important

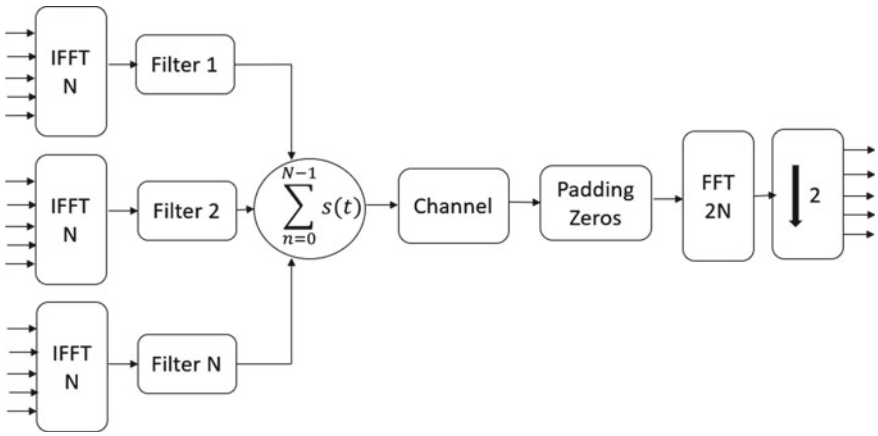

Fig. 5 Block diagram of UFMC

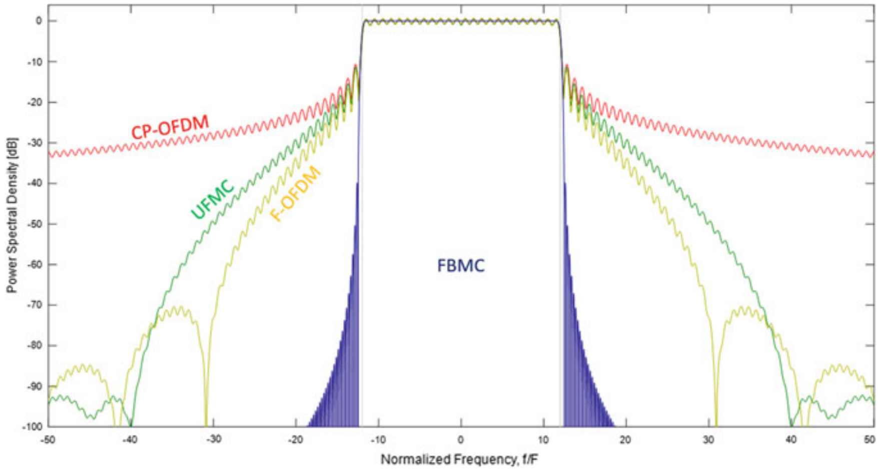

Fig. 6 Comparison of power spectral density of 5G candidates [14]

parameter for implementation of a communication technology. The comparison of computational complexity is shown in Fig. 7.

Parameters for the calculation of computational complexity are $L = 513$ (F-OFDM), $D = 12$, $M = 14$, $N = 1024$, $\text{NCP} = 72$, $N = 664$, and $L = 72$ (UFMC) [17]. The analysis of Fig. 7 shows that the CP-OFDM has the lowest computational complexity, and UFMC has highest computational complexity. However, FBMC and F-OFDM show almost similar performances.

The spectral efficiency of any modulation technique shows how efficiently the technique utilizes available bandwidth. Fig. 8 shows the spectral efficiency.

Comparison of 5G techniques. The analysis of spectral efficiency shows that FBMC and F-OFDM improved spectral efficiency over all other modulation techniques. CP-OFDM and UFMC shows almost similar performance. The bit error rate (BER) performance of 5G techniques is shown in Fig. 9. As shown in the analysis

Waveform	Number of Real Multiplications	Complexity Normalized
CP-OFDM	$M \times (2 \times (Nlog_2N - 3N + 4)$	1
F-OFDM	$M \times (2 \times (Nlog_2N - 3N + 4) + 2NL + 2NL + 2 * (N + NCP) \times L)$	4.84
FBMC	$M \times (2 \times (Nlog_2N - 3N + 4) + 4N + 8NP)$	5.71
UFMC	$M \times (2 \times (Nlog_2N - 6N + 4) + \frac{N}{D} \times (Nlog_2N - 3N + 4 + 2LN))$	601.89

Fig. 7 Comparison of computational complexity of 5G candidates

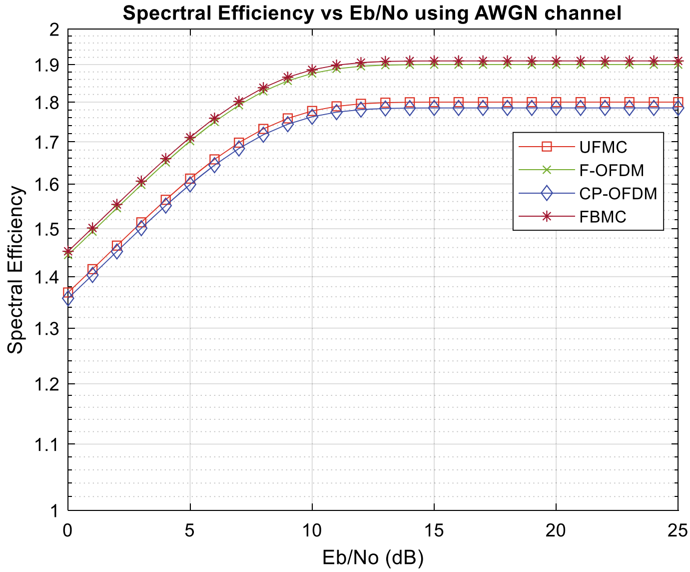

Fig. 8 Spectral efficiency comparison of 5G techniques

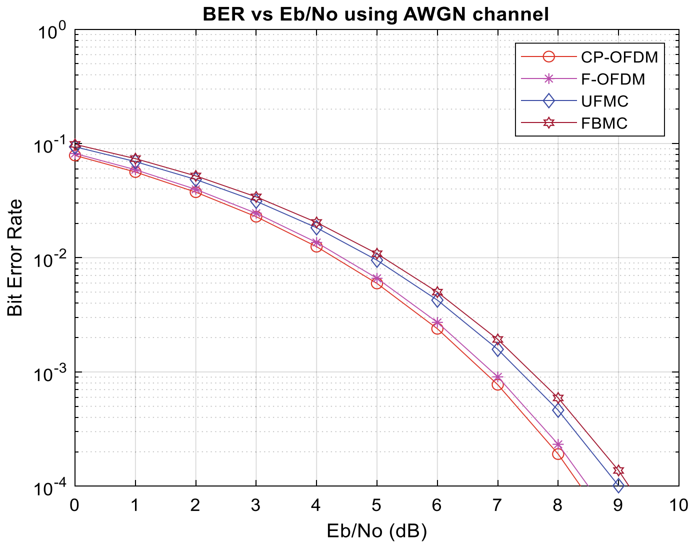

Fig. 9 Bit error rate comparison of 5G techniques

of BER of 5G modulation techniques, the CP-OFDM and F-OFDM show superior performance over UFMC and FBMC modulation techniques.

5 Conclusion

Extensive analysis of 5G—next-generation wireless technology candidates (CP-OFDM, F-OFDM, UFMC, FBMC) is provided in this paper. Computational complexity, power spectral density, BER, and spectral efficiency are used for the analysis of 5G modulation techniques. Computational complexity analysis shows that F-OFDM and FBMC outperform other filter-based modulation techniques. Analysis of power spectral density shows that the FBMC has the lowest out of band distortion. FBMC has the highest spectral efficiency than all other filter-based modulation techniques, but bit error rate performance is degraded. These next-generation wireless technologies will definitely bring revolution in the communication sector.

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