Design and Research on FBMC-OQAM Multicarrier Technology for 5G

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Abstract. Aimed at the low frequency utilization of OFDM due to adding cyclic prefix, a FBMC-OQAM system design based on frequency sampling prototype filter is proposed. In this paper, the performance difference between FBMC-OQAM and OFDM is studied by building the system model and the effect of the overlap factor of the prototype filter on the performance of multi-carrier technology in FBMC-OQAM system is also studied. It is verified that the system has high frequency utilization and good out-band suppression ability and it has good application value in 5G system.

1. INTRODUCTION

With the development of mobile communication technology, the fifth generation mobile communication system (5G) technical standards are constantly being constructed and improved, among which the multi-carrier technology is one of the key research areas. Orthogonal Frequency Division Multiplexing (OFDM) used in 4G system has some shortcomings, such as reduced spectral efficiency by using cyclic prefix (CP), using rectangular window to shape symbols in time domain results in high side lobe power, sensitive to frequency offset, high Peak to Average Power Ratio (PAPR). OFDM cannot meet the technical requirements of multi-carrier multiple access transmission in 5G multi-application scenario. Filter Bank Multicarrier with Offset Quadrature Amplitude Modulation (FBMC-OQAM) based on filter banks has outstanding advantages such as low spectrum side lobe leakage, none demanding of CP, no strict orthogonal synchronization and efficient implementation technology based on multi-phase filter structure. FBMC-OQAM has gradually become one of the hotspots in the research of 5G new multi-carrier technology.

2. PRINCIPLE OF FBMC-OQAM SYSTEM

2.1. System Framework

FFT is used for fast implementation of OFDM system and FFT algorithm is also used for fast implementation of FBMC-OQAM. Frequency Spreading-FFT (FS-FFT) and Poly Phase Network-FFT (PPN-FFT) are the most commonly used fast implementation schemes of FBMC-OQAM. Its computational complexity is lower than FS-FFT due to PPN-FFT can effectively suppress ISI without frequency expansion and cyclic prefix. Therefore, this paper uses PPN-FFT as a fast implementation scheme of FBMC-OQAM under this circumstance. Figure 1 shows the FBMC-OQAM system model.
FBMC-OQAM system mainly consists of four parts: OQAM preprocessing, OQAM post processing, SFB and Analysis Filter Bank (AFB). SFB module describes the process of fast inverse Fourier transform (IFFT) and multi-phase network (PPN), series-to-parallel transform (P/S) at the sender while AFB module describes the corresponding process at the receiver, such as FFT, PPN and S/P.

2.2. Transmitter

The specific working process of the sender in FBMC-OQAM system is described as follows. Firstly, after channel coding and symbol mapping of serial high-speed data, OQAM is used to modulate symbols. The purpose of OQAM preprocessing is to keep orthogonality between subcarriers. OQAM pretreatment processes complex symbols in real part and virtual part and interlaces half a symbol period in time interval to become transmission symbols. In this way, the real and imaginary parts of the interleaved delay are divided into subcarriers. Any subcarriers are orthogonal distribution at sampling time and adjacent subcarriers. Then IFFT operation is carried out on the transmission symbols and then the prototype filter banks with different offsets are filtered. Finally, the synthesized signals in the time domain are superimposed, sent out and thus it realizes the modulation of fast multi-carrier technology. The baseband signal processing at the transmitter is shown in Figure 2.
In Figure 2, $M$ represents the number of subcarriers and $h(t)$ the impulse response of the prototype filter. The signal of the sender is represented as:

$$x_{m,n} = a_{m,n} + j \times b_{m,n}$$

(1)

Among them, $a_{m,n} \text{ and } b_{m,n}$ represent the $m$-th subcarrier, the real part and the imaginary part of the n-th symbol, respectively.

The real part and imaginary part of FBMC-OQAM signal are orthogonal at $T/2$, where $T$ is the period of transmission signal. After modulation by prototype filter banks and $M$ subcarriers, the output signal is expressed as:

$$x_{m,n}(t) = [a_{m,n}h(t) + j \times b_{m,n}h(t - \frac{T}{2})]e^{j2\pi \frac{m}{M}(t-nM)}$$

(2)

Finally, the output signal of FBMC-OQAM transmitter is expressed as:

$$r(t) = \sum_{m=0}^{M-1} \sum_{n=0}^{L_p-1} [a_{m,n}h(t) + j \times b_{m,n}h(t - \frac{T}{2})]e^{j2\pi \frac{m}{M}(t-nM)}$$

(3)

2.3. Receiver

In this section the specific working process of the receiver in FBMC-OQAM system is represented. A set of prototype filters are also used, which have the same performance as the prototype filter banks at the transmitter and are symmetrical. Firstly, the original signal is filtered by prototype filter banks with different offsets. Then the original signal is recovered by FFT and OQAM. The post-processing of OQAM is to take the real part of the signal modulated to the subcarrier and then reconstruct the real signal into the complex signal through the mutual conversion of the real number and the complex number.

Assuming that the transmission channel is Additive White Gaussian Noise-AWGN, $\eta(t)$ denotes Gauss White Noise, $L_n$ denotes the maximum delay and the input signal of the receiver can be denoted as:

$$r(t) = \sum_{\tau=-L_n-1}^{L_n-1} h(\tau)s(t-\tau) + \eta(t)$$

(4)

After being processed by AFB at the receiving end, the corresponding demodulation signal can be obtained, which can be expressed as:

$$y_{m,n} = \sum_{\tau=-\infty}^{\infty} r(t) h(t - \frac{nm}{M})e^{-j2\pi \frac{m}{M}j(m+n)}$$

(5)

When the number of subcarriers is large, the fast implementation scheme of FBMC-OQAM system based on PPN-FFT reduces the computational complexity and is easy to be implemented.

3. DESIGN OF PROTOTYPE FILTER

In FBMC-OQAM system, a prototype filter with better time-frequency performance is used, which has higher spectral efficiency and good out-of-band suppression in frequency domain. In FBMC-OQAM system, PPN is usually obtained by a prototype filter, which determines the attenuation level of other sub-channels of each sub-channel, determines the performance of FBMC system and it is the core of filter bank multi-carrier system design.

The prototype filter design includes frequency sampling method, time-domain windowing method and direct optimization filter coefficient method. Frequency sampling method is used in the design of prototype filter in this paper. Frequency sampling method is a commonly used filter design method. The idea is to directly design better sampling points in frequency domain by using the frequency domain response expression of the filter and then obtain the time domain value of the filter through inverse Fourier transform.

Assuming that the designed prototype filter is a PHYDYAS filter bank, $h(t)$ is symmetrical and satisfies the approximate perfect reconstruction NPR condition in the actual channel. The filter length is $L_p$. $L_p = KM-1$, $K$ is the overlap factor of the prototype filter. $T$ is the sampling period. $M$ is the number of subcarriers in the system and $H_0$ is the coefficient of the prototype filter. For a system with complete transceiver and receiver terminals, the time domain impulse response expression of the transceiver prototype filter is as follows:
\[ h(t) = 1 + 2 \sum_{k=1}^{K-1} H_k^2 \cos(2\pi \frac{kT}{T_T}) \quad (6) \]

The corresponding frequency response expression of the transceiver prototype filter is as follows:

\[ H(f) = \sum_{k=-\infty}^{\infty} H_k^2 \frac{\sin(\pi(f - k/MK))}{MK \sin(\pi((f - k/MK)))} \quad (7) \]

It can be found that the PHYDYAS filter bank is the FFT filter bank when \( K = 1 \). The values of \( H_k \) are shown in Table 1 below. Values of \( H_k \) under different \( K \) conditions are shown in Table 1.

| \( K \) | \( H_0 \) | \( H_1 \) | \( H_2 \) | \( H_3 \) |
|-------|-------|-------|-------|-------|
| 1     | 1     | -     | -     | -     |
| 2     | 1     | \( \frac{\sqrt{2}}{2} \) | -     | -     |
| 3     | 1     | 0.911438 | 0.411438 | -     |
| 4     | 1     | 0.9719598 | \( \frac{\sqrt{2}}{2} \) | 0.235147 |

As shown in Figure 3, the power spectral density of FBMC-OQAM system when the prototype filter \( K = 4 \). Fig. 4 shows the power spectral density of the OFDM system when the prototype filter \( K = 1 \).

![Figure 3. Power spectral density of FBMC-OQAM system](image)

![Figure 4. Power spectral density of OFDM system](image)

The simulation results show that the prototype filter designed by frequency sampling method has low out-of-band leakage and out-of-band energy. It is a high frequency selective filter. Compared with the prototype filter of OFDM system, FBMC-OQAM system has obvious frequency characteristics.

4. SIMULATION RESULTS AND ANALYSIS

This system mainly designs and simulates FBMC-OQAM system based on PHYDYAS filter bank and compares, analyses the system performance. The simulation parameters of the system are shown in Table 2.

| Parameter                | Values  |
|--------------------------|---------|
| Number of subcarriers \( M \) | 512     |
| Overlap factor           | 2/4     |
| Filter length            | 2047    |
| The simulation number of times | 100     |
| Modulation mode | QPSK |
|-----------------|------|
| Wireless channel | AGWN |
| Length of input code | 6400 |
| Subcarrier bandwidth | 15KHz |
| Number of FFT samples | 1024 |

When the prototype filter takes different overlap factors, the system error code performance of FBMC-OQAM system is compared. Fig. 5 and Fig. 6 show the variation curve of system error rate with signal-to-noise ratio when $K = 4$ and $2$, respectively. The simulation results show that under the same SNR, the bigger the $K$ value is, the faster the error-code-rate decreases. However, the complexity of system implementation also increases. So in PHYDYAS filter banks the value of the overlap factor is set to 4.

![Figure 5. Error-code-rate curve with $K = 4$](image1.png)

![Figure 6. Error-code-rate curve with $K = 2$](image2.png)

The prototype filter is a 265-order low-pass filter. The center frequency $f_s$ is $2 \times 10^8$ Hz. The lower stopband cut-off frequency $f_{s\text{ top}}$ is $10.6 \times 10^6$ Hz and the passband cut-off frequency $f_{pass}$ is $7.5 \times 10^6$ Hz. Figure 9 shows normalized frequency response of the prototype filter and Fig. 10 shows normalized frequency response of multiphase filter group. The simulation results show the prototype filter adopts the direct frequency sampling method. Its stopband energy leakage is small and it has good time-frequency focusing. It can make the inter-carrier interference and inter-symbol interference within a certain threshold and ensure that the designed prototype filter meets the approximate perfect reconstruction conditions.
5. CONCLUSION
The simulation results show that the prototype filter design based on frequency sampling method makes FBMC-OQAM system have the advantages of good spectrum out-of-band suppression, no demanding of CP, high spectrum efficiency, no need for synchronization among carriers and suitable for fragmented spectrum utilization. The prototype filter designed in this paper can be used in 5G multi-carrier transmission FBMC/OQAM system and has strong practicability.

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