Research of Several Multicarrier Transmission Technologies in Mobile Communication

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Abstract. This paper describes the basic principles of OFDM(Orthogonal Frequency Division Multiplexing), FBMC(Filter Bank Multi-Carrier), UFMC(Universal Filtered Multi-Carrier), GFDM(Generalized frequency division multiplexing) and F-OFDM(Filtered-Orthogonal Frequency Division Multiplexing) in detail, and compares the performance characteristics and computational complexity of the five new modulation technologies. Studies have shown that, except for OFDM, the other four types of out-of-band leakage all are low, because FBMC and UFMC do not use CP, so they have high time-frequency efficiency, but the complexity is also increased accordingly. GFDM is a kind of independent block modulation with flexible frame structure, good robustness, lower complexity and good applicability. F-OFDM has fast sidelobe attenuation and high spectral efficiency, which can greatly suppress adjacent band interference through sub-band filter, meeting the needs of 5G rich service scenarios.

1. Introduction
In recent years, with the rapid development of mobile terminal equipment, data services are becoming more diversified and intelligent. Wireless communication technologies emerge in an endless stream and the update speed is also very fast, such as digital modulation technology from binary to multi-digit to new modulation orthogonal frequency division multiplexing (OFDM). It originated in the 1970s. After decades of development, it has been widely applied and deeply studied, especially in the fourth-generation mobile communication system and 802.16m. It has the advantages of high spectral efficiency, high resistance to frequency-selective fading or narrow-band interference, strong anti-fading ability, resistance to interference between signal waveforms, easy combination with multi-antenna technology (MIMO), low complexity of transceiver and so on. But at the same time, there are many shortcomings such as weak anti-carrier frequency offset, large peak mean, serious off-band power leakage, and the introduction of protection interval reduces the channel utilization rate. In particular, it must synchronize to maintain orthogonality between each subcarrier, with square wave as baseband waveform, besides bourbon disc is bigger and the introduction of the cyclic prefix CP makes wireless resource waste. While 5G supports a wealth of service scenarios, each of which has different requirements for transmission technology, therefore, a new modulation technology has been developed in the 5th generation mobile communication system to adapt to the new business requirements of 5G. The modulation technologies such as OFDM, FBMC, UFMC, GFDM and F-OFDM will be analyzed in principle below.

2. Principle analysis

2.1 OFDM
OFDM technology is a narrow-band modulation technology with multiple carriers. It firstly divides
the channel assigned by the system transmission signal into multiple orthogonal sub-channels, converts the high-speed data signal into a parallel low-speed sub-data stream, and then sends the signal to the channel for transmission. And the subcarriers are also orthogonal to each other, and their spectrums overlap each other. This method not only greatly reduces the complexity of receiver equalizer, but also avoids the interference between parallel data and the influence between adjacent channels.

Its schematic diagram is shown in figure 1. The signal data transmitted serially is firstly converted into the sub-data stream transmitted in parallel after flowing through the series in OFDM system, and then respectively to orthogonal sub-carrier modulation, then all the subcarrier signal superimposed together, and form a OFDM symbols on the channel transmission.Finally, the original data signal is obtained through the concatenation conversion.

\[ \text{Figure 1. Block diagram of OFDM principle} \]

2.2 FBMC

FBMC uses a set of parallel sub-band filters to filter multi-carrier signals. The principle is to achieve multicarrier modulation by compositing filter Banks at the transmitter and multicarrier demodulation by analyzing filter Banks at the receiver. The composite filter bank and the analysis filter bank are composed of a group of parallel member filters, in which each member filter is a modulation filter obtained by the carrier modulation of the prototype filter. It uses filter to segment the channel frequency spectrum so as to achieve the purpose of channel frequency reuse. Compared with OFDM, FBMC does not use rectangular window function, but obtains smaller side lobe by designing filter Banks such as Nyquist filter, so as to reduce the system's out of band attenuation, and it can provide a steeper slope at the edge of the signal band. In addition, each subcarrier does not need to be orthogonal, frequency protection with smaller, so there is no need to insert the cyclic prefix CP, and the prototype filter can be based on need through the interpolation operation design impact and frequency response, to achieve each sub-carrier bandwidth setting, each subcarrier between the overlapping degree of flexible control, thus flexible control, the interference between the adjacent sub-carrier and easy to use some scattered spectrum. At the same time, more subcarriers can be used for signal transmission, which saves the transmission bandwidth and further improves the spectral efficiency. Although the computational complexity of FBMC is higher than OFDM, more and more advanced signal processing and electronic equipment make the practical application of FBMC feasible. The specific principle block diagram is shown in figure 2.2.

\[ \text{Figure 2. Principle diagram of FBMC} \]
As can be seen from the schematic diagram of FBMC, it replaces CP with filter banks, so FBMC is not sensitive to carrier frequency deviation and improves frequency efficiency and energy efficiency at the same time. In order to reduce the computational complexity of FBMC, multiple network PPN filter structure is adopted. The specific implementation block diagram is shown in figure 2.3.

2.3 UFMC
Due to the large side lobe of OFDM, reserved protection band and filtering OFDM technology are mostly used to achieve multiple access transmission in practice. UFMC system structure diagram is shown in figure 2.4.

Filter OFDM adds filter compression sidelobe to each OFDM symbol, and UFMC turns to filter on a set of continuous subcarriers (e.g. Each group of subcarriers of UFMC constitutes a subband, and the subbands do not overlap each other and CP is not used, resulting in intercarrier interference (ICI) within the same subband, which needs to be balanced at the receiver. At the same time, for inter-symbol interference (ISI) caused by filtered time-domain trailing, it sets the time-domain protection interval, so it does not improve the spectral efficiency compared with CP system. At the cost of increasing the complexity of transmitter and equalizer, subband synchronization is not required.

It filters a set of continuous subcarriers, and the number of subcarriers is configured according to the actual application. When the number of subcarriers of each group is 1, UFMC becomes FBMC transmission. Therefore, FBMC is a special case of UFMC, so UFMC is also called OFDM of universal filtering.

2.4 GFDM
GFDM is a multi-carrier transmission scheme with high spectral efficiency, simple transmission and reception, small out-of-band power leakage, and no synchronization between sub-bands. The symbol
blocks on $S$ time slots and $M$ subcarriers are treated as one frame, and the filtering process at the sending end is transformed into circular convolution by designing a set of filter related operations, which saves the CP length consumed by the trailing end of the sending filter. Unlike OFDM, CP is added to each subcarrier rather than after modulation. The receiver uses first-order frequency domain equalization, and ICI can be completely eliminated by double-sic technology.

GFDM transceiver principle as shown in figure 5, the sender, the binary sequences encoded data stream and then by a mapping to generate data block vector QAM symbols, each vector is assigned to each symbol on the sub-carrier, repass GFDM modulation including string and transform, sampling, cyclic convolution and subcarrier sum GFDM signal process, finally introduced the length of the cyclic prefix is greater than the delay spread, is used to resist the intersymbol interference caused by multipath channel, sending it out through the channel; The receiver is its inverse process, and the effect of multipath channel is compensated by frequency domain equalization technology.

Figure 5. Principle block diagram of GFDM transceiver

2.5 F-OFDM
F-OFDM is a new 5G air port multi-carrier waveform modulation technology proposed by huawei. It divides the entire system bandwidth into multiple sub-bands through sub-band filter Banks, and each sub-band can flexibly configure waveform parameters according to the actual application scenarios. F-OFDM system with low complexity, strong anti-interference ability and high time-frequency resource utilization is designed and implemented. It is one of the modulation technologies adopted by 5G standard and commercialized. Each sub-band of f-ofdm can be considered as non-overlapping, so the leakage outside the band is small, which can not only improve the spectral efficiency, but also effectively use the scattered spectrum to achieve coexistence with other waveforms. At the same time, F-OFDM is divided into different subbands according to different services, and different TTI, subcarrier intervals and CP lengths are configured in each subband, so as to realize flexible and adaptive 5G air port technology, to support dynamic soft air port parameter configuration of 5G according to business requirements, and to improve the flexibility and scalability of 5G system. Its schematic diagram is shown in figure 2.6.

Figure 6. Principle diagram of F-OFDM
3. Comparison of modulation techniques

The five modulation technologies such as OFDM, FBMC, UFMC, GFDM and F-OFDM have their own characteristics, and the comparison of each index is shown in table 1.

Table 1 Comparison of modulation technologies

|                        | OFDM | FBMC | UFMC | GFDM | F-OFDM |
|------------------------|------|------|------|------|--------|
| CP?                    | None | None | None | exist | exist  |
| Filtered in the sender?| None | Exist (Linear convolution) | Exist (Linear convolution) | Exist (Cyclic convolution) | exist  |
| Filtered in the receiving end? | None | Exist (Linear convolution) | None | Exist (Cyclic convolution) | exist  |
| Modulation symbols way | no limit | OQAM | no limit | no limit | no limit |
| Combination with MIMO  | easy | More difficult | More difficult | easy | easy  |
| peak-to-average ratio  | high | high | medium | low | high  |
| Out of band leakage    | high | low | low | very low | low  |
| Spectrum efficiency    | high | high | high | medium | high  |
| PSD performance        | low | high | medium | medium | medium |
| complexity             | low | high | high | medium | medium |
| orthogonality          | yes | yes | yes | no | yes  |
| ISI                    | high | high | high | medium | high  |
| Synchronization        | high | low | low | medium | low  |
| requirements           | long | long | short | short | medium |
| Time delay             | compatible | compatible | compatible | compatible | compatible |
| compatibility          | compatible | compatible | compatible | compatible | compatible |

Table 2 Analysis of computational complexity

Table 2 roughly analyzes the implementation complexity of OFDM, FBMC, UFMC, GFDM and f-ofdm. The total number of carriers is N, and M subcarriers are actually used. The measurement of complexity is the multiplication times required to send S M symbol streams, and FBMC overlap factor K is generally 4.

| Modulation mode | Complexity of transmitter | Complexity of receiver |
|-----------------|---------------------------|------------------------|
| OFDM            | $SN\log_2 N$              | $SN\log_2 N + M$       |
| FBMC            | $SK(N\log_2 N + 2M + N\log_2 K)$ | $SK(N\log_2 N + 2M + N\log_2 K)$ |
| UFMC            | $S[N\log_2 N + 2N + M\log_2 M]$ | $S[N\log_2 N + M\log_2 M]$ |
| GFDM            | $S[N\log_2 N + (N + M)\log_2 M]$ | $S[N\log_2 N + (N + M)\log_2 M]$ |
| F-OFDM          | $SN\log_2 N + M\log_2 M$  | $SN\log_2 N + M\log_2 M$ |

4. Conclusion

In general, FBMC is an asynchronous transmission scheme with high spectral efficiency, low implementation complexity and no CP. Because of the use of OQAM technology, the combination with MIMO is not as easy as OFDM. GFDM retains CP, which has flexible frame structure. It can be adapted to different types of business, and the implementation is relatively simple. UFMC uses short filter length, which can support short packet service, but is not suitable for some specific application
scenarios. F-OFDM can make use of scattered frequency band, with small out-of-band leakage and large sidelobe attenuation, which saves scattered spectrum resources needed by 5G due to extensive service strain, thus improving service flexibility and spectrum utilization.

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