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Filter Bank based Multi-Carrier Systems in 5G Network

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Abstract

Most current fourth generation wireless systems use OFDM modulation technique. The success of the multi-carrier OFDM technology lies in the many benefits they offer. OFDM is robust against multipath effects, provides good spectral efficiency and better use of frequency resources compared to other conventional multi-carrier modulations. However, OFDM has some major drawbacks as a loss of spectral efficiency due to the insertion of the guard interval, a very high level of side lobes causing leakage of power between different subcarriers. OFDM technology will then be abandoned in favor of multi-carrier technology based filter bank called FBMC (Filter Bank Multicarrier). Through this article, we will see the Filter Bank multi-carriers (FBMC) based on theory of filter bank, and then we will look at FBMC/ OQAM technical, probably the most popular among FBMC techniques used in context of 5G wireless communication systems.

Key-words: *5G*; *FBMC*; *FBMC/ OQAM*; *OFDM*.

Résumé

La plupart des systèmes sans fil actuels de quatrième génération utilisent la technique de modulation OFDM. Le succès rencontré par les techniques multi-porteuses OFDM réside dans les nombreux avantages qu'elles offrent. La technique OFDM est très robuste aux effets des trajets multiples, offre une bonne efficacité spectrale et une meilleure utilisation des ressources fréquentielles par rapport aux autres modulations multi-porteuses classiques. Toutefois, l'OFDM présente quelques inconvénients majeurs comme une perte de l'efficacité spectrale suite à l'insertion de l'intervalle de garde, un niveau très élevé des lobes latéraux entrainant une fuite de puissance entre les différentes sous-porteuses. La technique OFDM va alors être délaissée au profit des techniques multi-porteuses à base de banc de filtres appelées FBMC (Filter Bank MultiCarrier). A travers cet article, nous allons voir le principe de la modulation multiporteuses a base de banc de filtres, puis nous examinerons la techniques FBMC / OQAM, probablement la plus populaire parmi les techniques FBMC utilisées dans le contexte des systèmes de communication sans fil 5G.

Mots-clés : *5G*; *FBMC*; *FBMC/OQAM*; *OFDM*

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1. Introduction

Orthogonal frequency division multiplexing (OFDM) has been shown to be an effective technique to combat multipath fading in wireless communications. That's why many current technologies like DVB (digital video broadcasting), 802.11a, WiMax, LTE / LTE-Advanced (long term evolution) are adept. [1] [2].

OFDM multi-carrier techniques offer many advantages:

- ✓ Very effective way to combat the effects of multipath fading such as interference between symbols by inserting the cyclic prefix.
- ✓ Optimal spectral size compared to other multi-carrier techniques conventional.
- ✓ Easy and effective implementation of modulation and demodulation thanks to fast Fourier transforms.
- ✓ Robustness against impulsive noises.
- ✓ Simplicity of equalization.

Despite its many strengths, the OFDM technique can be limited by some disadvantages:

- ✓ The insertion of the guard interval causes a considerable loss of spectral efficiency.
- ✓ The signal spectrum has extremely high side lobes generating also a loss of spectral efficiency and a power leak between the subcarriers

In order to improve spectral efficiency, the multi-carrier technique based on filter banks has been proposed. [3]

The main difference between OFDM and FBMC modulations lies in the property of spectral leakage.

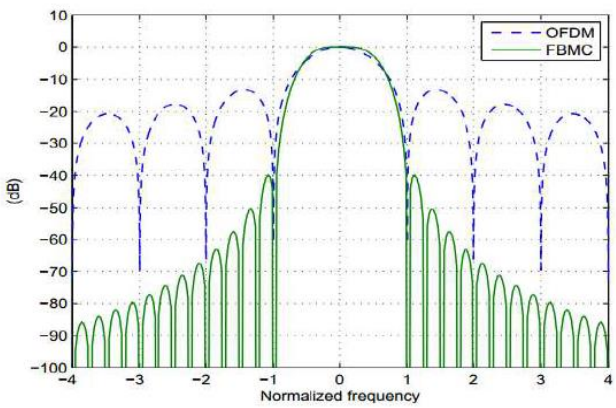

Fig. 1. Frequency comparison of OFDM and FBMC

According to Fig. 1, the OFDM modulation exhibits important side lobes while the FBMC modulation has negligible side lobes in the frequency domain.

The FBMC / OQAM technique has the following characteristics:

- ✓ No cyclic prefix is needed
- ✓ Because of its weak side lobes, the FBMC / OQAM technique is much less sensitive to time offsets than the OFDM technique.
- ✓ The FBMC / OQAM technique is less sensitive to residual frequency shift and is more robust to the Doppler Effect.

2. Orthogonal Frequency Division Multiplexing (OFDM)

In OFDM multicarrier system, the frequency spectrum of the subcarriers is overlapped with the least frequency spacing and the orthogonality is attained amid the various subcarriers. In Fig. 2, the input stream is subdivided into parallel data streams by means of the serial to parallel (S/P) converter, that are then passed into an inverse fast Fourier transformation (IFFT) block to produce time sequence of the streams. Consequently, by totaling a cyclic prefix (CP), the OFDM symbol time sequences are extended. The CP is a copy of the latter portion of the symbol that is added in the start of the sequence and should be greater than the network deferral spread in order to diminish the inter symbol interference (ISI) produced by the influx of various OFDM symbols with distinct delay. The resultant digital signal is transformed into analog form and transmitted over the channel [4]. At the receiver end, the signal is reconstructed into digital form and the fast Fourier transform (FFT) is achieved in the received streams after eradicating the CP [5]. Finally, the parallel streams are collected into a single stream as the original transmitted one. Some of the disadvantages of OFDM are enumerated below:

1) Decreased spectral efficiency owing to the CP employed;
2) High spectral leakage owing to the rectangular windowing;
3) Interference amid the unsynchronized signal in the neighbouring bands.

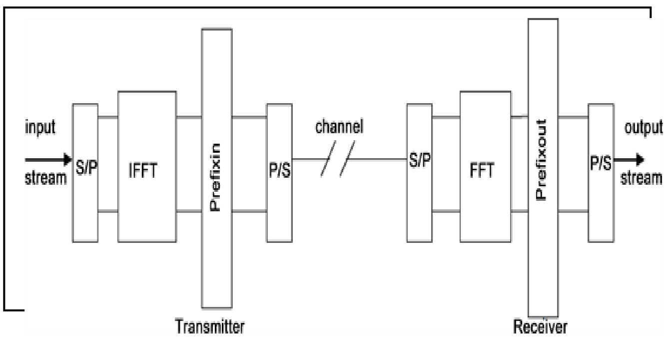

Fig. 2. Block diagram of orthogonal frequency division multiplexing].

3. Filter Bank Multi Carrier FBMC

The FBMC technique overcomes the limitations of OFDM by adding generalized pulse shaping filters which delivers a well localized sub channel in both time and frequency domain. Consequently, FBMC systems have more spectral containment signals and offer more effective use of the radio resources where no CP is required. In Fig 3 it can be seen that the filter banks on the transmitter side and the receiver side consist of an array of N filters that processes N input signals to give N outputs. If the inputs of these N filters are associated together, the system in analogous manner can be measured as an analyzer to the input signal based on each filter characteristics.

In Fig 3 the filter bank used at the transmitter side is called synthesis filter bank and the filter bank used in receiver side is called analysis filter bank. As depicted in Figure 3 the input signal is first converted from serial to parallel form and then passed through synthesis filter bank and then it is converted back to serial form after coming out of synthesis bank. After this it can be seen in Figure 2 that in the receiver side after the signal passes through the channel it is converted to parallel form by serial to parallel converter and passed through analysis filter bank.

Finally when the output signal is obtained it is again converted to serial form by parallel to serial converter. [6]. Hence the synthesis-analysis configuration depicted in Figure 3 is called transmulitplexer or TMUX and is applied in the MC communication systems [7].

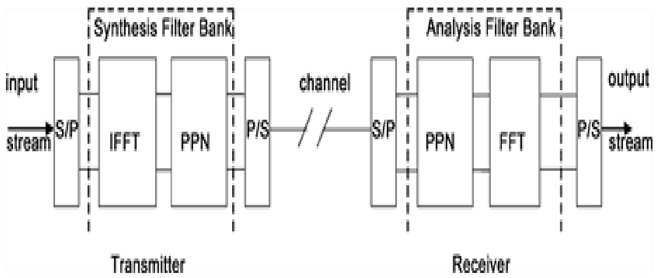

Fig. 3. Block diagram of filter bank multi carrier (FBMC)

4. Transmultiplexer Configuration of FBMC

The core of the FBMC system is the TMUX configuration presented in Fig 4 the main processing blocks in this direct form depiction are OQAM pre-processing, synthesis filter bank, the analysis filter bank, and the OQAM post-processing. The transmission channel is classically misplaced when analysing and planning TMUX systems as the channel equalization problem is controlled distinctly. The synthesis and analysis filter banks are naturally the key components. As already mentioned, the Field of filter banks is very broad and even modulated filter banks can be divided into different types depending on the choice of the prototype filters, modulation functions, and desired properties.

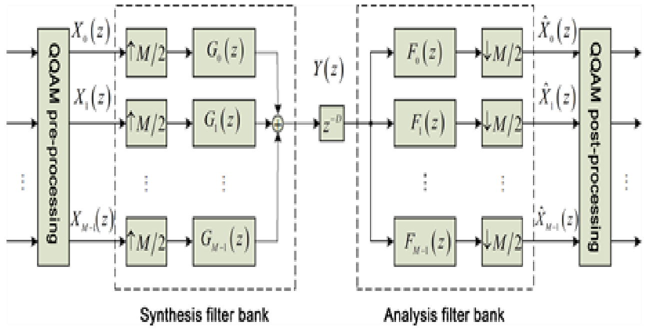

Fig. 4. TMUX configuration of FBMC

FBMC chooses the Nyquist filter (such as classical raised cosine filter) to reduce the out-of-band radiation. Actually, modulation and demodulation are coupled in the network. Consider the normalization of data, we often use half-Nyquist filter (such as the square root raised cosine filter). In this paper, we use PHYDYAS filter. Table 1 shows the frequency coefficients of prototype filter when K=4, where K denotes the overlapping factor.

Table 1. The frequency coefficients of prototype filter when k=4

H_0	H_1	H_2	H_3
1	0.971960	$\sqrt{2}/2$	0.235147

The frequency response of the prototype filter is

$$H(f) = \sum_{k=-(K-1)}^{K-1} H_k \frac{\sin\left(\pi\left(f - \frac{k}{MK}\right)MK\right)}{MK\sin(\pi\left(f - \frac{k}{MK}\right))} \qquad (1)$$

M denotes the number of subcarriers. The time response of the prototype filter is

$$h(t) = 1 + 2\sum_{k=1}^{K-1} H_k \cos\left(2\pi\frac{kt}{KT}\right) \qquad (2)$$

5. OQAM Pre/Post Processing

The TMUX system transmits OQAM symbols instead of QAM symbols. The pre-processing block, which utilizes the transformation between QAM and OQAM symbols, is shown in Fig 5. As can be seen, the first operation is a simple complex-to-real conversion, where the real and imaginary parts of a complex-valued symbol $C_{k,l}$ are separated to form two new symbols $d_{k,2l}$ and $d_{k,2l+1}$ (this operation can also be called as staggering). So the order of these original symbols depends upon the sub channel number, i.e., the conversion is distinct for even and odd numbered sub channels. The complex-to-real conversion upsurges the sample rate by a factor of 2. After this the second operation is the multiplication by $\emptyset_{k,n}$, sequence. A possible choice is

$$\emptyset_{k,n} = j^{(k+n)} \tag{3}$$

However, it should be noted that the signs of the $\emptyset_{k,n}$ sequence can be chosen arbitrarily, but the pattern of real and imaginary samples has to follow the above definition. For example, an alternative sequence:

$$\emptyset_{k,n} = \begin{Bmatrix} 1, j, 1, j \ldots for\ k\ even \\ j, 1, j, 1 \ldots for\ k\ odd \end{Bmatrix} \tag{4}$$

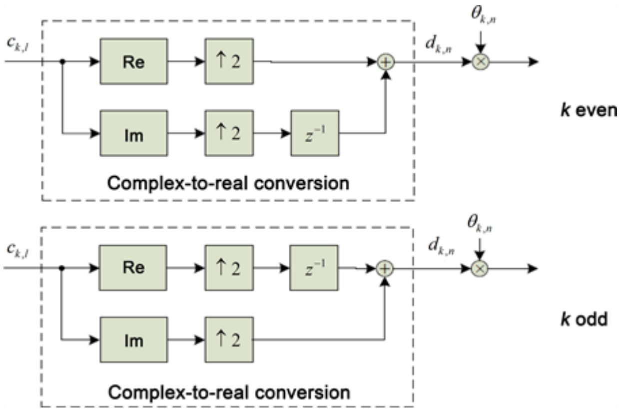

Fig. 5. OQAM preprocessing

The input signals are purely real or imaginary-valued after the OQAM pre-processing. The post-processing block is shown in Figure 6 and again there are two slightly different structures depending on the sub channel number. The first operation is the multiplication by $\emptyset^*_{k,n}$ sequence that is followed by the operation of taking the real part. The second operation is real-to complex conversion, in which two successive real-valued symbols (with one multiplied by j) form a complex-valued symbol; $\hat{c}_{k,n}$ (this operation is also called as de-staggering). The real-to-complex conversion decreases the sample rate by a factor 2. As can be seen, the first operation is a simple complex-to-real conversion, where the real and imaginary parts of a complex-valued symbol $c_{k,l}$, are separated to form two new symbols $d_{k,l}$ and $d_{k,l+1}$ (this operation can also be called as staggering). The order of these new symbols depends on the sub channel number, i.e., the conversion is different for even and odd numbered sub channels. The complex-to-real conversion increases the sample rate by a factor of 2. The second operation is the multiplication by sequence $\emptyset_{k,n}$ [8] [9].

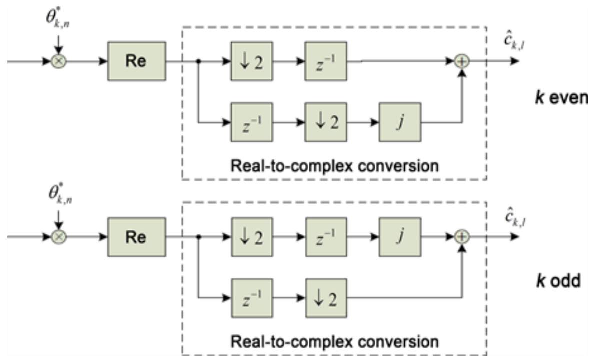

Fig. 6. OQAM post processing

6. Simulation Results

The analysis compares Filter Bank Multi-Carrier (FBMC) modulation with generic OFDM modulation. FBMC offers ways to overcome the known limitations of OFDM of reduced spectral efficiency and strict synchronization requirements. The benefits have led it to being measured as one of the modulation techniques for 5G communication structures.

Power spectral density of the FBMC transmit signal is designed to give the low out-of-band leakage. In Fig 7 and Fig 8 the plots of the spectral densities for OFDM and FBMC schemes are compared. In Fig 7 it depicts that the FBMC has lesser side lobes. This lets an advanced utilization of the allotted spectrum, leading to advanced spectral efficiency.

In Fig 8 the OFDM PSD curve has higher side lobes and out of band leakage. Hence the FBMC scheme is more advantageous in comparison to OFDM by providing higher spectral efficiency. Owing to the per subcarrier filtering, it suffers a larger filter delay (in comparison to UFMC) and also needs OQAM processing.

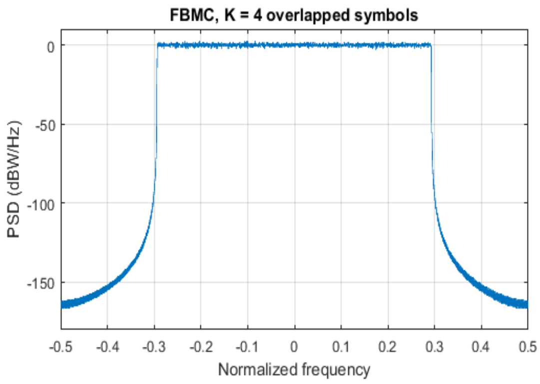

Fig.7. The power spectral density of the FBMC

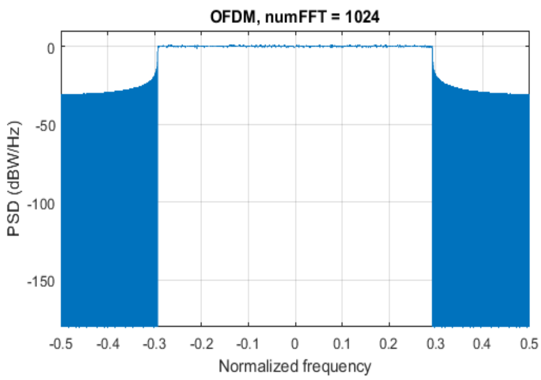

Fig.8. The power spectral density of the OFDM

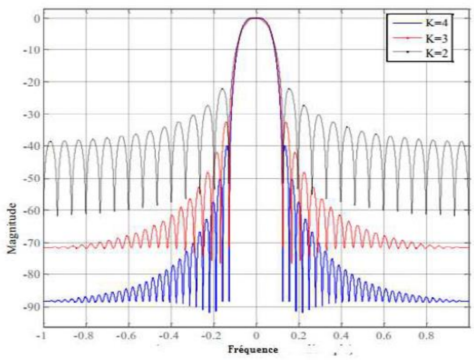

Fig.9. Frequency response of the PHYDYAS prototype filter

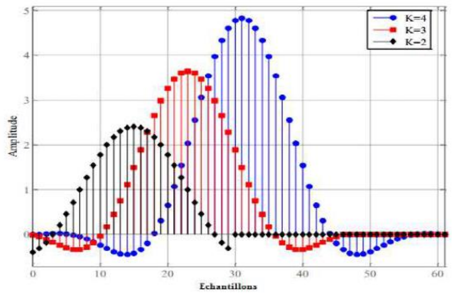

Fig.10. Impulse response of the PHYDYAS prototype filter

The main difference between FBMC and OFDM is the choice of the prototype filter. Such that OFDM uses a rectangular window filter and FBMC using a prototype filter designed with the Nyquist pulse shaping principle, which can reduce greatly the spectral leakage problem of OFDM. This results in negligible ICI and ISI. In Fig 1 the magnitude responses of prototype filters of FBMC and OFDM have been compared against the normalized frequency taken on the x axis.

Fig 9 and 10 give respectively the frequency response and the impulse response of a prototype filter used in a FBMC / OQAM system with different values of K. From Fig 6 it can be seen that the optimal value of the overlap factor in terms of sideband suppression is K = 4. The difference between the main lobe and the first side lobe for K = 4 is about 40 dB

7. Conclusion

In this paper the performance comparison of OFDM and the FBMC as the most potential contenders of 5G has been carried out and simulated using MATLAB in terms of Power Spectral Density curves of OFDM and FBMC, sub channels of OFDM and FBMC, and the prototype filter comparisons of FBMC and OFDM. All the simulations performed show that the FBMC technique is the most promising waveform contender for future wireless communications specially 5G telecommunications. The shortcomings of OFDM technique have been addressed and removed by the FBMC. FBMC is evolved from OFDM.

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