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Low Complexity Transceiver Design for FBMC-OQAM System for Future Generation Wireless Communication

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Abstract: This paper proposes a new structure for the FBMC-OQAM (filter bank multicarrier with offset quadrature amplitude modulation) system aiming to reduce computational complexity which is one of the main technical challenges faced and tackled by many baseband signal research groups. The new structure depends on the application of the filter bank in the frequency domain instead of the time domain. As a result, this structure provides a low computational complexity compared to the original structure, where only IFFT (Inverse Fast Fourier Transforms) blocks and simple multiplication and addition operations are needed. Simulation results were performed by analyzing the number of multiplication and addition operations, in addition to studying the performance of the FBMC-OQAM system of the new structure by simulating the BER (bit error rate) in terms of SNR (signal-to-noise ratio).

Key words: FBMC-OQAM, IFFT, BER, SNR.

1. Introduction

Since the launch of the first digital mobile telecommunications networks in the 1990s, the amount of data transmitted on these networks has steadily increased from year to year. The steady growth of mobile data traffic has been accompanied by successive improvements in mobile telecommunications standards. In general, when you want to increase the bit rate of a transmission, you must clear the symbol duration. However, the presence of a multipath channel has the effect of introducing ISI (inter-symbol interference), which requires a complex equalization of reception. Thus, multi-carrier modulations have been proposed as an alternative solution to counter the effects of multipath channels.

Orthogonal frequency-division multiplexing (OFDM) [1] is the most widely used multi-carrier modulation and is used in many wireless communications systems such as Wi-Fi IEEE 802.11 [2], WiMax IEEE 802.16 [3], LTE [4], and so on. Nevertheless, OFDM modulation has some disadvantages. First of all, the addition of the cyclic prefix causes a loss of spectral efficiency because the cyclic prefix is only a copy of some symbols already transmitted, which reduces the effective rate. On the other hand, the use of a rectangular filter generates significant side lobes, which means that the signals transmitted on the edges of the band are harmful to the other systems occupying the adjacent bands. These drawbacks motivated researchers to develop other alternative solutions such as multi-carrier modulations based on filter banks (filter bank multi-carrier (FBMC)).

FBMC [5] uses a well-located frequency shaping filter, which greatly reduces the out-of-band spectrum overflows effect. Thus, a larger number of subcarriers can be used from an allocated band. In FBMC-OQAM (filter bank multicarrier with offset quadrature amplitude modulation) [6], each subcarrier is modulated with the OQAM modulation, and the orthogonality condition is maintained in the real domain. Indeed, the transmitted data are carried by the

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real part of the received symbols, and their imaginary part represents the intrinsic interference of the FBMC-OQAM modulation.

One of the major FBMC-OQAM modulation drawbacks is the computational complexity, which is the interest of many researchers in this field. Wen et al. [6] derived a method to reduce the computational complexity of causal FBMC-OQAM modulators. Its principle is to take advantage of the complex conjugation relations characterizing the outputs of the IFFT (Inverse Fast Fourier Transforms) stage. Nadal et al. [7] proposed a novel low-complexity pipeline implementation for FBMC-OQAM transmitter. It is based on the use of a pruned IFFT algorithm and on the proposal of novel architectures related to all constituent blocks. While in the proposal a new design and prototyping experience of an advanced communication system was based on FBMC-OQAM modulation.

In this paper, we propose a new FBMC-OQAM structure to reduce computational complexity. It consists of the application of the bank filter in the frequency domain instead of the time domain. This structure provides a low computational complexity compared to the conventional structure, where, only two IFFT blocks and simple multiplication and addition operations are needed for the calculation of two convolution operations. Simulation results given by the BER (bit error rate) versus SNR (signal-to-noise ratio) show the merit of this approach.

2. Model System

If supposedly, there is a need to transmit $M \times N$ complex input symbols in an OQAM-FBMC system over N tones, then the m^{th} input symbol vector, can be written as:

$$\boldsymbol{X}_m = \left(X_{m,0}\ X_{m,1} \dots X_{m,N-1}\right)',\ 0 \le m \le M-1 \quad (1)$$

where, $(.)'$ is the transpose operator and the m^{th} symbol over k^{th} sub-carrier is denoted $X_{k,m}$. It is noticed that in an OQAM-FBMC system, real symbols are transmitted at interval $\frac{T}{2}$ [8], where, T is the time period of an OQAM-FBMC symbol. The OQAM mapping of the complex input symbol vectors $\{\boldsymbol{X}_m\}_{m=0}^{M-1}$ into real symbols $\{a_{m',k}\}_{m'=0}^{2.M-1}$ is as shown below:

$$a_{m',k} = \begin{cases} (1-\beta).R_m^k + \beta.I_m^k,\ m' \textit{ is even} \\ \beta.R_m^k + (1-\beta).I_m^k, m' \textit{ is odd} \end{cases} \quad (2)$$

$$m' = \begin{cases} 2m, m' \textit{ is even} \\ 2m+1, m' \textit{ is odd} \end{cases} \quad (3)$$

$$\beta = k \textit{ modulo } 2, 0 \le k \le N-1 \quad (4)$$

where, R_m^k and I_m^k are the real and imaginary parts of the complex elements in $\{\boldsymbol{X}_m\}_{m=0}^{M-1}$. In OQAM, a time staggering of $\mathrm{T}/2$ is done on the real or on the imaginary parts of the complex symbols $X_{k,m}$. Then, the obtained real symbols undergo the poly-phase filtering of a prototype filter [9]; namely PHYDYAS filter [10]. The obtained discrete-time OQAM-FBMC signal $x(n)$ is given by:

$$x(n) = \sum_{m'=0}^{2.M-1} \sum_{k=0}^{N-1} a_{m',k}.h(n - m'\frac{NL}{2})\, e^{j\frac{2\pi k}{LN}n} e^{j\varphi_{m',k}} \quad (5)$$

where, $0 \le n \le (M+3.5)NL-1$, and $h(n)$ is the prototype filter impulse response designed based on frequency sampling technique with length of 4 LN, and $\varphi_{m',k} = \frac{\pi}{2}(k+m') - \pi k m'$.

3. Low Complexity FBMC-OQAM

The transmitted signal $x(n)$ in Eq. (5) can be divided into two signals, as follows:

$$x(n) = x_1(n) + x_2\left(n - \frac{NL}{2}\right) \quad (6)$$

We can write $x(n)$, as follows:

$$x(n)=\sum_{m=0}^{M-1}\sum_{k=0}^{N-1}a_{2m,k}.h(n-mNL)\,e^{j\frac{2\pi k}{LN}n}e^{j\varphi_{1,m,k}}+\sum_{m=0}^{M-1}\sum_{k=0}^{N-1}a_{2m+1,k}.h\left(n-mNL-\frac{NL}{2}\right)e^{j\frac{2\pi k}{LN}n}e^{j\varphi_{2,m,k}} \quad (7)$$

where $\varphi_{1,m,k}=\pi m+\frac{\pi}{2}k$ and $\varphi_{2,m,k}=\pi m+\frac{\pi}{2}k+\frac{\pi}{2}$. From the last term of the equation above, we can conclude from the expression of $x_2(n)$ as:

$$x_2(n)=\sum_{m=0}^{M-1}\sum_{k=0}^{N-1}a_{2m+1,k}.h(n-mNL)\,e^{j\frac{2\pi k}{LN}n}e^{j\varphi_{2,m,k}} \quad (8)$$

which has the same expression form as $x_1(n)$. Now, setting $n=l+pNL$ with $l\in\{0,1,\dots,N-1\}$ and $p\in Z$, we can write the first signal term $x_1(n)$ as:

$$x_1(n)=\sum_{m=0}^{M-1}\sum_{k=0}^{N-1}a_{2m,k}e^{j\frac{2\pi k}{LN}l}e^{j\varphi_{1,m,k}}h(l+(p-m)NL) \quad (9)$$

We can write $x_1(n)$, as follows:

$$x_1(l+pNL)=\sum_{m=0}^{M-1}B_l[m]h[l+(p-m)NL] \quad (10)$$

where, $B_l[m]=\sum_{k=0}^{N-1}a_{2m,k}e^{j\frac{2\pi k}{LN}l}e^{j\varphi_{1,m,k}}$, can be seen as the outputs of an M-IFFT block whose inputs are $a_{2m,k}e^{j\frac{2\pi k}{LN}l}e^{j\varphi_{1,m,k}}$. In the same way, we can write the signal $x_2(n)$ as:

$$x_2(l+pNL)=\sum_{m=0}^{M-1}Q_l[m]h[l+(p-m)NL] \quad (11)$$

where, $Q_l[m]=\sum_{k=0}^{N-1}a_{2m+1,k}e^{j\frac{2\pi k}{LN}l}e^{j\varphi_{2,m,k}}$, is the outputs of an M-IFFT block whose inputs are $a_{2m+1,k}e^{j\frac{2\pi k}{LN}l}e^{j\varphi_{2,m,k}}$.

Therefore, considering the polyphase component $h_l(p)$, which operates at a rate of $1/NL$, of the prototype filter $h(m)$ as:

$$h_l(p)=h(l+pNL) \quad (12)$$

We obtain:

$$\begin{cases} x_1(l+pNL)=\sum_{m=0}^{M-1}B_l[m]h_l(p-m) \\ x_2(l+pNL)=\sum_{m=0}^{M-1}Q_l[m]h_l(p-m) \end{cases} \quad (13)$$

It follows that each sample of the signals $x_1(n)$ or $x_2(n)$ can be obtained by convolving each k^{th} IFFT output signal with the k^{th} polyphase component $h_k(n)$, and then multiplexing all the resulting sequences of the M branches into one sequence by using a parallel-to-serial converter (P/S). Fig. 1 depicts the implementation scheme of the IDFT and the polyphase network generating $x_1(n)$, where $H_k(z)$ is the Z transform of $h_k(n)$. Hence, because the transmitted signal is $x(n)=x_1(n)+x_2(n-NL/2)$, the direct implementation of IDFT-PPN approach for the transmitter requires two chains, or a single IDFT running at rate $2/NL$ and two identical PPN devices as shown in Fig. 2.

4. Analysis of Computational Complexity

For the sake of simplicity, the number of additions is not considered, because multiplication requires much higher computation complexity than addition. Assuming that N is a power of 2, the number of RMs (real multiplications) of N point IFFT is given as $(2N.L)\log_2(N.L)$, where factor 4 denotes the number of RMs per one complex multiplication. For a fair comparison of complexity, we assume that the $4N$ point IFFTs with $3N$ zero padding are used in all the schemes being compared. The numbers of RMs for the 4N point IFFT with 3N zeros padded to the input are given as $4\times[(2N.L\log_2(N.L)+NL)]$. The PPN needs $32NL$ RMs per symbol duration. The conventional FBMC-OQAM transmitter requires two IFFT operations and two PPNs. Therefore, the n_{mul} for the conventional FBMC-OQAM scheme

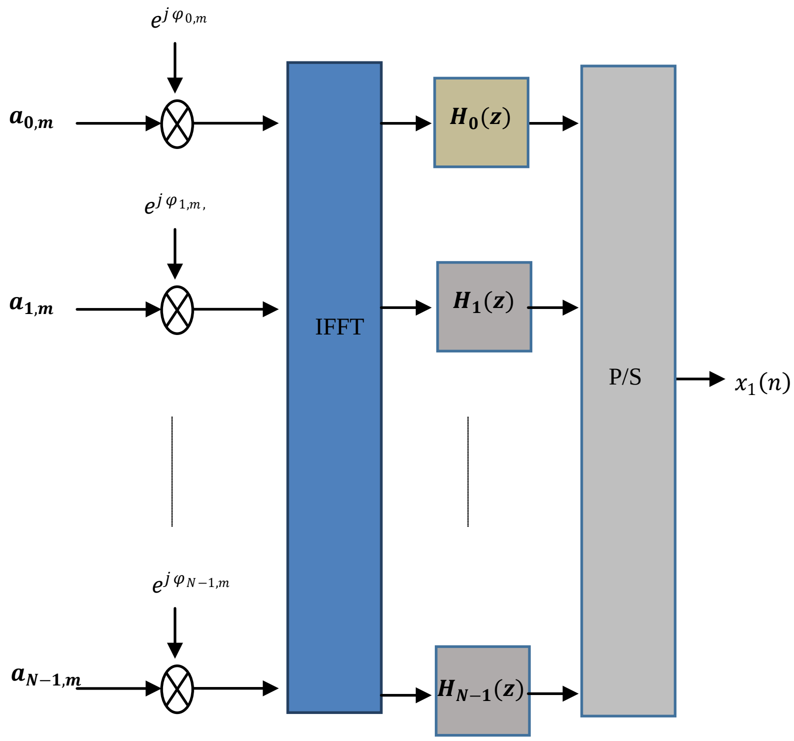

Fig. 1 Implementation scheme of the IFFT and the polyphase network (PPN) for a single chain.

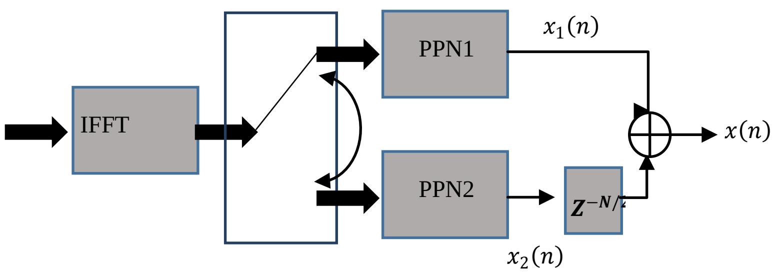

Fig. 2 Implementation scheme of the FBMC-OQAM transmitter using one IFFT and two polyphase networks.

is $8 \times [(2N.Llog_2(N.L) + NL)] + 64NL$. As for the proposed FBMC-OQAM scheme, it requires just two IFFT blocks to calculate B_l and Q_l as well as two convolutions to calculate x_1 and x_2. Therefore, the n_{mul} for the proposed FBMC-OQAM scheme is $(NL)\log_2(N.L) + 8\,NL$. For instance, with $N = 256$ and $L = 4$, the proposed FBMC-OQAM scheme needs only about 31.5% RMs compared to conventional FBMC-OQAM scheme.

5. Simulation Results

In simulation tests, we have considered the FBMC-OQAM system with various levels of modulation (4, 16, 32, 64 and 256) and a fixed number of subcarriers (256). Also, we have used an oversampling factor $L = 4$, a CC (convolution coding) scheme with rate coding equal to ½, a constraint length of 7, a first register $(g_1 = 133)$ and second register $(g_2 = 171)$. Moreover, the FBMC-OQAM system considers the number of overlap time symbol $M = 16$. Table 1 gives the simulation parameters.

5.1 BER Performance

Fig. 3 compares BER performance versus SNR of the FBMC-OQAM signal with different values of

Table 1 Simulation parameters.

Symbol	Quantity	Value
QAM	Modulation method	$\{2, 4, 5, 6, 8\}$ bit per symbol
CC	Channel coding	$\{7, 133, 171\}$
N	Number of sub-carriers	256
M	Number of overlap time symbol	140
h(n)	PHYDYAS filter	-
L	Oversampling factor	4
Rician, Rayleigh	Channel	

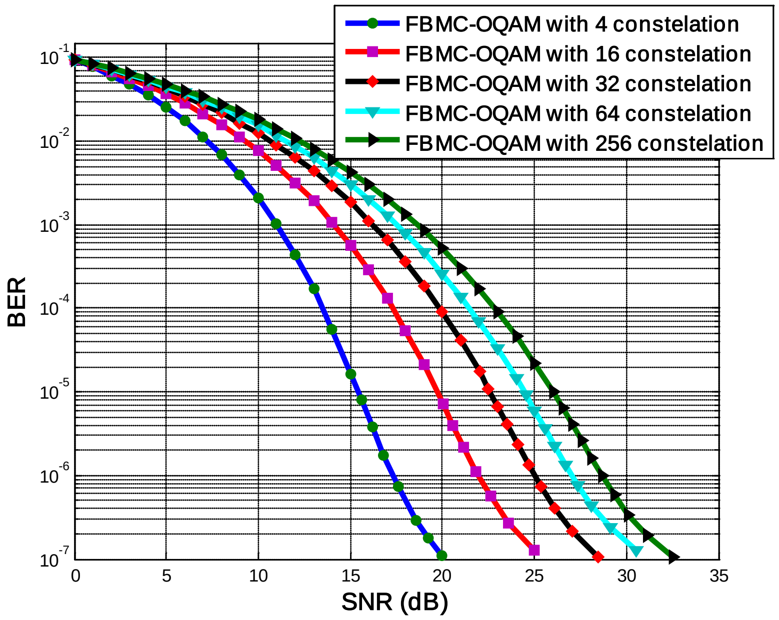

Fig. 3 BER performances of FBMC-OQAM scheme for different constellation value over AWGN channel.

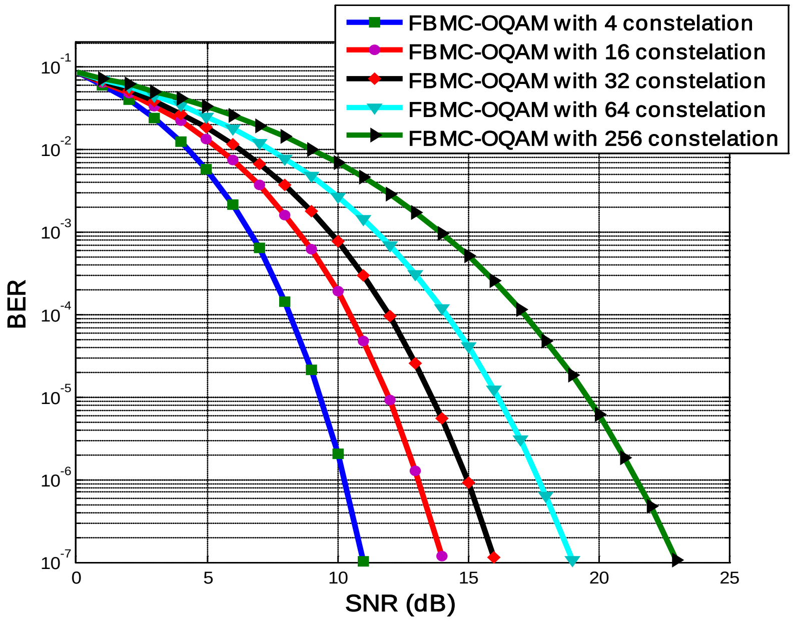

Fig. 4 BER performances of FBMC-OQAM scheme for different constellation value over Rayleigh fading channel.

constellation, at different IBO values over AWGN (Additive White Gaussian Noise) channel. We can see that the lowest SNR value was achieved when 4 constellations were used with a value of 11 dB at BER = 10^{-7}, more and more the constellation number being bigger, the SNR value increases, to achieve 14 dB, 16 dB, 18 dB, and 23 dB for 16 constellations, 32 constellations, 64 constellations, and 256 constellations, respectively.

Fig. 4 compares BER performance versus SNR of the FBMC-OQAM signal for different level of modulation at different point of constellation number value over Rayleigh fading channel. It can be seen that for a target BER of 10^{-7} the lowest SNR value of 20 dB is required with the lowest modulation level 4. For a fixed BER target (i.e. 10^{-7}) as the modulation level increases, the required SNR increases also. For instance, the required SNR for modulation levels of 16, 32, 64 and 256 is 25, 27, 31 and 33dB respectively.

6. Conclusion

The FBMC-OQAM is considered as a key element of the future air 5G interfaces. It has a better spectrum shape and improves mobility support compared to OFDM. Therefore, the availability of efficient hardware implementations becomes of great interest. In this paper new prototype architecture of the transmitter for giving a low complexity is proposed and compared to conventional FBMC-OQAM implementation. The proposed architecture allows a 31.5% complexity reduction in computational complexity compared to a typical conventional FBMC-OQAM transmitter, making this modulation scheme particularly attractive from the point of view of performance and reliability.

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