Filter Bank Multicarrier to Reduce Intrinsic Interference in MIMO Systems

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***Abstract*: Filter-bank multicarrier (FBMC) transmission system was projected as a substitute method to orthogonal frequency division multiplexing (OFDM) system since it has a higher spectral efficiency. One of the features of FBMC is that the demodulated transmitted symbols are accompanied by interference terms caused by the adjacent transmitted data in time-frequency domain. The occurrence of this interference is an issue for some multiple-input multiple-output (MIMO) systems and until today their grouping with FBMC remains an open problem. We can cite, among these methods, the Alamouti scheme and the maximum likelihood detection (MLD) with spatial multiplexing (SM). In this paper, we shall suggest a new FBMC scheme and transmission strategy with IOTA Algorithm and PHYDAS Algorithm in order to avoid this interference term. This suggested scheme (called FFT- FBMC) alters the FBMC system into an equivalent system formulated as OFDM irrespective of some residual interference. Thus, any OFDM transmission technique can be performed directly to the proposed FBMC scheme with a equivalent complexity growth compared to the classical FBMC. First, we will develop the FFT-FBMC in the case of single-input single-output (SISO) configuration. Then, we extend its application to SM-MIMO configuration with MLD and Alamouti coding scheme. Simulation results show that FFT-FBMC can almost reach the OFDM performance, but it remains slightly outperformed by OFDM.**

***Keywords*: FBMC, OFDM, MIMO, MLD, IOTA, SISO.**

1. Introduction

The OFDM technology is widely used in two types of working environments, i.e., a wired environment and a wireless environment. When used to transmit signals through wires like twisted wire pairs and coaxial cables, it is usually called as DMT(digital multi-tone). For instance, DMT is the core technology for all the DSL (digital subscriber lines) systems which provide high-speed data service via existing telephone networks. However, in a wireless environment such as radio broadcasting system and WLAN (wireless local area network), it is referred to as OFDM. Since we aim at performance enhancement for wireless communication systems, we use the term OFDM throughout this thesis. Furthermore, we only use the term MIMO-OFDM while explicitly addressing the OFDM systems combined with multiple antennas at both ends of a wireless link.

The history of OFDM can all the way date back to the mid1960s, when Chang published a paper on the synthesis of band limited orthogonal signals for multichannel transmission. He presented a new principle of transmitting signals simultaneously over a band limited channel without the ICI and the ISI. Right after Chang's publication of his paper, Saltsburg demonstrated the performance of the efficient parallel data transmission systems in 1967, where he concluded that "the strategy of designing an efficient parallel system should concentrate on reducing crosstalk between adjacent channels than on perfecting the individual channels themselves". His conclusion has been proven far-sighted today in the digital baseband signal processing to battle the ICI. Through the developments of OFDM technology, there are two remarkable contributions to OFDM which transform the original "analog" multicarrier system today's digitally implemented OFDM. The use of DFT (discrete Fourier transform) toper form baseband modulation and demodulation was the first milestone when Weinstein and Ebert [4] published their paper in 1971. Their method eliminated the banks of subcarrier oscillators and coherent demodulators required by frequency-division multiplexing and hence reduced the cost of OFDM systems. Moreover, DFT-based frequency-division multiplexing can be completely implemented in digital baseband, not by band pass filtering, for highly efficient processing. FFT, a fast algorithm for computing DFT, can further reduce the number of arithmetic operations from N3 to N log N (N is FFT size). Recent advances in VLSI (very large scale integration) technology has made high-speed, large-size FFT chips commercially available. In We Einstein's paper [4], they used a guard interval between consecutive symbols and the raised-cosine windowing in the time-domain to combat the ISI and the ICI. But their system could not keep perfect orthogonality between subcarriers over a time dispersive channel. This problem was first tackled by Peeled and Ruiz [6] in 1980 with the introduction of CP (cyclic prefix) or cyclic extension. They creatively filled the empty guard interval with a cyclic extension of the OFDM symbol. If the length of CP is longer than the impulse response of the channel, the ISI can be eliminated completely.

2. System model

Let us denote the trans multiplexer impulse response obtained in equation (4) by f (k0)(Δn). The proto type filters are designed in a way that they provide a well-localized spectrum and spread over only a few adjacent subcarriers. The most important interference comes from the same considered subcarrier and immediate neighboring ones. Without loss of generality and for the sake of simplicity, we consider only the interference coming from adjacent subcarriers. Hence, we can split (3) into three terms and write

$$r_{k,n} \cong \underbrace{\sum_{i=-\Delta}^{\Delta} f_0^{(k)}(i) a_{k,n-i}}_{t_k} + \underbrace{\sum_{i=-\Delta}^{\Delta} f_0^{(k-1)}(i) a_{k-1,n-i}}_{t_{k-1}} + \underbrace{\sum_{i=-\Delta}^{\Delta} f_{-1}^{(k+1)}(i) a_{k+1,n-i}}_{t_{k+1}},$$

where $a_{k,n}$ are the inputs of the FBMC modulator on the k subcarrier and the n the time instant, $f^{(k)}_j(i)$ are the coefficients of the trans multiplexer impulse response when the impulse is applied on the k the subcarrier, Δ = 2K − 1 is the one side maximum response spread in time domain. Hence, i /∈[−Δ, Δ] ⇒ f(k)j (i) = 0.

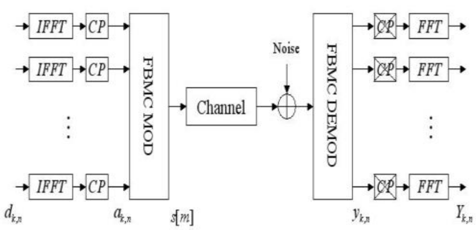

Fig.1 FBMC Trans Multiplexer

Filter bank multicarrier modulation is a development of OFDM that overcomes some its short comings enabling higher throughput date rates. Filter Bank Multi Carrier, FBMC is a form of multi-carrier modulation that is being investigated for some future high data rate wireless and cellular systems. FBMC is a derivative of orthogonal frequency division multiplexing, but it overcomes some of its shortcomings. It has a much better usage of the available capacity and is able to offer higher data rates within a given radio spectrum bandwidth. One of the main shortcomings arises from the fact that OFDM requires the use of what is termed a cyclic prefix. The cyclic prefix is essentially a copy of part of a transmitted symbol in OFDM that is appended at the beginning of the next. This redundancy reduces the throughput of the transmission and also wastes power. A further disadvantage of OFDM is that spectral localization of the subcarriers is weak and this results in spectral leakage and interference issues with unsynchronized signals. Filter bank multicarrier is a development of OFDM. Using banks of filters that are implemented, typically using digital signal processing techniques, FBMC. When carriers were modulated in an OFDM system, side lobes spread out either side. With a filter bank system, the filters are used to remove these and therefore a much cleaner carrier results.

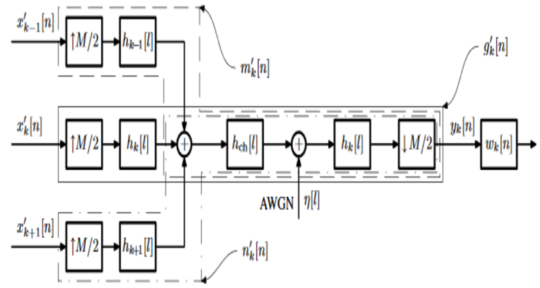

Fig. 2. FBMC structure

A. FBMC vs. OFDM

FBMC is an advancement of OFDM. The modulators of OFDM and FBMC are shown in Fig.1. The only fundamental change is the replacement of the OFDM with a multicarrier system based on filter banks, wherein the IFFT plus CP in is replaced by

B. OFDM structure

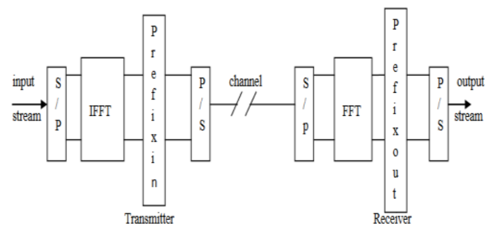

Fig. 3. Block diagram of OFDM

C. FBMC structure

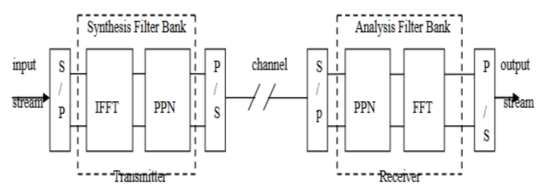

Fig. 4. Block diagram of Filter Bank FBMC.

D. IOTA Algorithm

In the past, orthogonal frequency division multiplexing (OFDM) has enjoyed its dominance as the most popular signaling method in broadband wired and wireless channels. OFDM has been adopted in the broad class of DSL standards as well as in the majority of wireless standards. Attempts to design filters that satisfy the orthogonality conditions and at the same time approach the Heisenberg-Gabor uncertainty lower bound as close as possible have been made and design methods have been developed. The design presented in is called isotropic orthogonal transform algorithm (IOTA) filter. IOTA design/algorithm was first introduced in a patent by Alard. The designs proposed in, on the other hand, are referred to as Hermite pulses, reflecting the fact that their construction is based on a linear combination of a set of Hermite functions. In the rest of this section, we limit our emphasis to the design of Hermite pulses and emphasize the flexibilities that these designs provide in adopting to doubly dispersive channels. The design procedure proposed by Haas and Belfiore constructs an isotropic function. Note that it is an isotropic function with parameter. Moreover, it can be shown that the set of functions for are also isotropic, with the same parameter. This implies that the construction for any set of coefficients leads to an isotropic function. In, the coefficients have been calculated to construct a filter that satisfies the set of constraints (for parameters. Haas and Belfiore's design allows transmission of QAM symbols with a density of symbol per unit area in the time-frequency space. This design of may also be used as the prototype filter in a CMT or SMT structure to increase the density to 2 PAM symbols per unit area, equivalent to one QAM symbol. Examples of both designs are presented later. In the rest of this section, we follow the approach of to present a broad class of Hermite filter designs that includes the design presented in as a special case. The filter bank multicarrier (FBMC) transmission technique leads to an enhanced physical layer for conventional communication networks and it is an enabling technology for the new concepts and, particularly, cognitive radio. The objective of this document is to provide an overview of FBMC, with emphasis on the features which impact communication networks. The only prerequisite for reading the document is basic knowledge in digital signal processing, in particular sampling theory, fast Fourier transform (FFT) and finite impulse response (FIR) filtering. OFDM exploits a given frequency bandwidth with a number of carriers, while FBMC divides the transmission channel associated with this given bandwidth into a number of sub-channels. In order to fully exploit the channel bandwidth, the modulation in the sub channels must adapt to the neighbor orthogonality constraint and offset quadrature amplitude modulation (OQAM) is used to that purpose. The combination of filter banks with OQAM modulation leads to the maximum bit rate, without the need for a guard time or cyclic prefix as in OFDM. The effects of the transmission channel are compensated at the sub-channel level. The sub channel equalizer can cope with carrier frequency offset, timing offset and phase and amplitude distortions, so that asynchronous users can be accommodated. When FBMC is employed in burst transmission, the length of the burst is extended to allow for initial and final transitions due to the filter impulse response. These transitions may be shortened if some temporary frequency leakage is allowed, for example whenever a frequency gap is present between neighboring users. As a multicarrier scheme, FBMC can benefit from multi antenna systems and MIMO techniques can be applied. Due to OQAM modulation, adaptations are necessary for some MIMO approaches, in the diversity context.

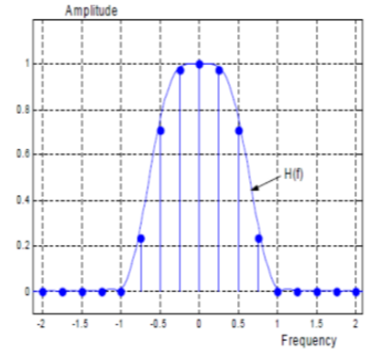

Fig. 5. Proto type filter frequency coefficients and frequency response k=4

3. The proposed scheme

A. FBMC

Filter-bank multicarrier (FBMC) transmission system was proposed as an alternative approach to orthogonal frequency division multiplexing (OFDM) system since it has a higher spectral efficiency. One of the characteristics of FBMC is that the demodulated transmitted symbols are accompanied by interference terms caused by the neighboring transmitted data in time-frequency domain. The Alamouti scheme and the maximum likelihood detection (MLD) with spatial multiplexing (SM). The transmission strategy is to avoid interference term. The proposed scheme (called FFT- FBMC) transforms the FBMC system into an equivalent system formulated as OFDM regardless of some residual interference.

B. FBMC/OQAM modulation

The considered FBMC/OQAM system is transmitting offset quadrature amplitude modulation (OQAM) symbols [4, 16], where the in-phase and the quadrature components are time staggered by half a symbol period, T/2. Moreover, for two adjacent subcarriers, if we consider that the time delay T/2 is introduced into the imaginary part of the QAM symbols on one of the subcarriers, then it is introduced into the real part of the symbols on the other one Accordingly, the baseband continuous-time model of the FBMC/OQAM transmitted signal can be defined as follows In FBMC systems, any kind of modulation can be used whenever the sub-channels are separated. For example, if only the sub-channels with even (odd) index are exploited, there is no overlap and QAM modulation can be employed. However, if full speed is seeked, all the sub-channels must be exploited and a specific modulation is needed to cope with the frequency domain overlapping of the neighboring sub-channels.

1) Transmission systems

In transmission systems, a channel is inserted between the transmitter and the receiver and it introduces a number of impairments, such as amplitude and phase distortion, timing offset, frequency offset and noise. The impact of these impairments and the way to counter them in the multicarrier context depend on how the multicarrier system is exploited. This is the so-called offset quadrature amplitude modulation (OQAM) and the term 'offset' reflects the time shift of half the inverse of the sub-channel spacing between the real part and the imaginary part of a complex symbol. Note that this type of modulation is used in single carrier systems, to improve the peak factor. In the present multicarrier context, the throughput rate is the same as with QAM modulation, employed for example in OFDM systems, but without the guard time. A data element is applied to one input of the IFFT and it modulates one carrier. Ina filter bank with overlapping factor K, as shown in Fig.5, a data element modulates 2K-1carriers. Thus, the filter bank in the transmitter can be implemented as follows- an IFFT of size KM is used, to generate all the necessary carriers, - a particular data element, after multiplication by the filter frequency coefficients, is fed to the 2K-1 inputs of the IFFT with indices (i −1) K +1, ..., (i +1) K −1.

Practically, the data element is spread over several IFFT inputs and the operation can be called "weighted frequency spreading". For each set of input data, the output of the IFFT is a block of KM samples and, since the symbol rate is 1/M, K consecutive IFFT outputs overlap in the time domain. Therefore, the filter bank output is provided by an overlap and sum operation. at the transmitter side, the discrete time FBMC signal as follows [2]

$$s[m] = \sum_{k=0}^{M-1} \sum_{n \in Z} a_{k,n} g[m - nM/2] e^{j\frac{2\pi}{M}k(m-\frac{D}{2})} e^{j\phi_{k,n}} \quad (1)$$

Where M is an even number of subcarriers, g[m] is the prototype filter taking values in real field, $\frac{D}{2}$ is the delay term which depends on the length (L) of g[m]. We have D=KM-1 and L =KM,

Where, K is the overlapping factor. The transmitted symbols a k, n are real valued symbols which are the real or imaginary parts of QAM symbols. $\phi_{k,n} = \frac{\pi}{2}(n+k) - \pi nk$ an additional phase term. we can rewrite (1) in a simple manner

$$s[m] = \sum_{k=0}^{M-1} \sum_{n \in Z} a_{k,n} g_{k,n}[m]. \quad (2)$$

Where $g_{k,n}[m]$ are shifted versions of g[m] in time and frequency. In this case of no channel, the demodulated symbol over k' th subcarrier and the n' th instant is determined using the inner product of s[m] and $g_{k',n'}[m]$

$$r_{k',n'} = \langle s, g_{k'}, n' \rangle = \sum_{m=-\infty}^{+\infty} s[m] g^{*}_{k',n'}[m]$$

$$= \sum_{m=-\infty}^{+\infty} \sum_{k=0}^{M-1} \sum_{n \in Z} a_{k,n} g_{k,n}[m] g^{*}_{k',n'}[m]. \quad (3)$$

The trans multiplexer impulse response can be derived assuming null data except at one time-frequency position (k0,n0) Where a unit impulse is applied. Then, equation (3) becomes

$$r_{k',n'} = \sum_{m=-\infty}^{+\infty} g_{k_0,n_0}[m] g^{*}_{k',n'}[m]$$

$$\sum_{m=-\infty}^{+\infty} g[m] g[m - \Delta n M/2] e^{j\frac{2\pi}{M}\Delta k(\frac{D}{2}-m)} \times e^{j\pi(\Delta k + k_0)\Delta n} e^{-j\frac{\pi}{2}(\Delta k + \Delta n)} \quad (4)$$

Where $\Delta n = n' - n_0$ and $\Delta k = k' - k_0$. We notice that the impulse response of the trans multiplexer depends on the k0. Indeed, the sign of some impulse response coefficients exploits this property. several pulse shaping prototype filters g[m] can be used according to their properties. In this pulse shape based on the so-called Isotropic Orthogonal Transform Algorithm (IOTA) function introduced by A lard [5].The second one is referred as the PHYDAS prototype filter proposed by Bellanger in [3]. The overlapping factor of both pulse shapes is k=4. All the prototype filters g[m] are designed to satisfy the real orthogonality condition given by [2]

$$\Re e\left\{ \sum_{m=-8}^{\infty} gk', n'[m] gk', n[m] \right\} = \delta_k k' \delta_{n,n'} \quad (5)$$

Let us consider the SISO FBMC Transmission .When passing through the radio channel and adding noise contribution $\gamma_{k',n'}$,equation(3) becomes [10]

$$\gamma_{k',n'} = h_{k',n'} a_{k',n'} + \gamma_{k',n'} + \underbrace{\sum_{(k,n)\neq(k',n')} h_{k,n} a_{k,n} \sum_{m=\infty}^{+\infty} g_{k,n}[m] g*_{k',n'}[m],}_{I_{k'n'}} \quad (6)$$

Where, $h_{k',n'}$ is the channel coefficient at subscriber k' and time index and the term is defined as an intrinsic interference. The most part of the energy of the impulse response is localized in a restricted set around the considered symbol. Consequently , we assume that the intrinsic interference term depends only on this restricted set moreover, assuming that the channel is constant at least over this summation zone, we can write as in[10]

$$\gamma_{k',n'} \approx h_{k',n'}(a_{k',n'} + \hat{I}_{k',n'}) + \gamma_{k',n'} \ldots\ldots\ldots \quad (7)$$

$$\hat{I}_{k',n'} = \sum_{(k,n)\in\Omega_{k',n'}} a_{k,n} \sum_{m=\infty}^{+\infty} g_{k,n}[m] g_{k',n'}[m].$$

According to (5) and because is real valued, the intrinsic interference $\hat{I}_{k',n'} = ju_{k'n'}$ is pure imaginary. Thus, the demodulated signal can be given by

$$\gamma_{k',n'} \approx h_{k',n'}(a_{k',n'} + ju_{k',n'}) + \gamma_{k',n'}$$

FBMC techniques have the potential to enhance the performance of synchronized.

2) Guard interval reduction

The main drawback of the proposed scheme is the insertion of the CP in each subcarrier. Despite that the FBMC impulse response is spread over $2\Delta = 4K-2$ time periods, we can reduce the CP in order to decrease the spectral efficiency loss but at the expense of performance degradation. In fact, reducing the CP causes an ISI and Inter block interference. Clearly, the performance depends on the ratio between the signal and the interference power (SIR).

Since the values of $f_0^{(k)}(\Delta n)$ are known (they depend only on the prototype filter), we can evaluate the SIR for each value of $n \in \Omega^{(k)}$ and for the different values of L. Equation (9)shows that the received signal can be considered as the sum of three terms. First, let us consider only the first term T k, and after, the same developments can be applied to the other terms.

Guard interval in FBMC:

Let us denote by $a_k = [a_k, 0, ..., a_k.N-1]^T$ the N-point IFFT output at the k thsubcarrier which is expressed by

$$a_k = W^H d_k$$

where $d_k = [d_{k,0},..d_{k,N-1}]^T$, and W^H is the N-point IFFT matrix. According to the transmission strategy the data vector d_k contains zero elements in either its first or second half depending on the parity of k.

When the CP length is shorter than the maximum spread (2Δ), interference terms are added to the term T_k. Let us consider a received block , after CP removal, at the k th subcarrier $y_k = [y_{k,0,........,}y_{k,N-1}]^T$, We can write

$$y_k = F_{0,k} a_k + r_1 + r_2 + r_3, \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where $r_1 = -Aa_k, r_2 = B_1 a_k^+$ and $r_3 = B_2 a_k^-$,where a_k^+ and a_k^- are respectively the blocks transmitted previously and subsequently at the same k th subcarrier . $F_{0.k}$ is an $N \times N$ circulant matrix with entries given by

$$F_{0,k(p,q)} = f_0^{(k)}\left(\left|p-q+\frac{N}{2}\right|_N - \frac{N}{2}\right),$$ for

$$(p,q) \in \{0,....,N-1\}^2 .$$

$B_1 = T_u P_L,,,,,, B_2 = T_I P_{-L}$,where the upper triangular matrix T_u is given by $T_{u(p,q)} = f_0^{(k)}(p-q+N+L)$

With $0 \le p \le N-1, p \le q \le N-1,$ and the lower Triangle matrix T1 is given by

$$T_1(p,q) = f_0^{(k)}(p-q-N-L)$$

With $0 \le q \le N-1, q \le p \le N-1,$ Matrix A is given by

$$A = T_u P_{-L} + T_1 P_L,$$

Where PL is a permutation matrix that circularly shifts the columns to the left by L positions. All of B1,B2 and A are sparse matrices, and when $L \ge 2\Delta,$ these matrices are zero.

Demodulating Yk by taking the N-point FFT, we obtain the output vector

$$Y_k = W_{yk}$$

Replacing B1,B2 and A by their expressions , we obtain

$$Y_k = WF_{0,k}W^H d_k - WT_u P_{-L} W^H d_k - WT_1 P_L W^H d_k .$$

$$+ WT_u P_L W^H d_k^+ + WT_1 P_{-L} W^H d_k^-$$

Since the matrix F0,k and the permutation matrices PL and P-L are circulant matrices, we can write

$$F_{0,k} = W^H \bar{F}_{0,k} W$$

And

$$P_L = W^H E_L W ,$$

Such that EL and $\bar{F}_{0,k}$ are diagonal matrices. Hence , the last equation become

$$Y_k = \bar{F}_{o,k} d_k - (\bar{T}_u E_{-L} + \bar{T}_1 E_L) d_k + \bar{T}_u E_L d_k^+ + \bar{T}_1 E_{-L} d_k^-,$$

Where $\bar{T}_u = WT_u W^H$ and $\bar{T}_1 = WT_1 W^H$. The diagonal elements of $\bar{F}_{0,k}$ are given by

$$\bar{F}_{0,k}(n,n) = \sum_{p=-\frac{N}{2}}^{\frac{N}{2}-1} f_0^{(k)}(p) e^{-j2\pi\frac{np}{N}}$$

And those of EL are given by $E_{L(n,n)} = e^{j2\pi \frac{nL}{N}}$.

Let us denote by D the diagonal matrix which contains the diagonal elements of the term $\bar{T}_u E_{-L} + \bar{T}_1 E_L$ and $T = \bar{T}_u E_{-L} + \bar{T}_1 EL - D$. This last matrix represents the ISI in the same data vector. Thus, we can rewrite as

$$Y_k = (\bar{F}_{0,k} - D)d_k - Td_k + \bar{T}_u E_L d_k^+ + \bar{T}_1 E_{-L} d_k^- \quad \ldots.. \quad (9)$$

The elements of the matrices $\bar{T}_u = WT_u W^H$ and $\bar{T}_1 = WT_1 W^H$ are respectively given by

$$\bar{T}_1(m,n) = \frac{1}{N}\sum_{q=0}^{N-1}\sum_{p=0}^{N-1-q} f_0^{(k)}(p - L_0)e^{-j2\pi\frac{mp}{N}} e^{j2\pi\frac{(n-m)q}{N}}, \quad (10)$$

$$\bar{T}_u(m,n) = \frac{1}{N}\sum_{q=0}^{N-1}\sum_{p=0}^{q} f_0^{(k)}(L_0 - p)e^{-j2\pi\frac{mp}{N}} e^{j2\pi\frac{(n-m)q}{N}}, \quad \ldots \quad (11)$$

Where $L_0 = N + L$. According to (10), we have $f_0^{(k)}(p) = (f_0^{(k)}(-p))^*, \forall p \in$ □ .Hence , we can easily show that the entries of matrix T can be expressed as

$$T(m,n) = \left\{ 2e^{-j\pi\frac{n-m}{N}} \Re e\{G(m,n)e^{j\pi\frac{n-m}{N}}\},\right.$$

for $n \neq m$ ….. (12)

Where $G(m,n) = \frac{1}{N}\sum_{q=0}^{N-1}\sum_{p=0}^{q} f_{0(k)}(L_0 - p)e^{j2\pi\frac{(n-m)q}{N}} e^{-j2\pi\frac{nl}{N}}$

Also, we show that the diagonal matrix D has elements

$$D(n,n) = 2\Re e\left\{\sum_{p=L+1}^{L+N}(p-L)f_0^{(k)}(p)e^{-j2\pi\frac{np}{N}}\right\}. \quad .. \quad (13)$$

Until now, we have considered only the first term T k in (9). Regarding the other terms, we can proceed in the same way. Moreover, let us relax the assumption made in sub-section 3-A which consisted in considering only the interference coming from the immediate neighboring subcarriers. Therefore , we consider all possible terms $T_{k=1}$ with $|l| = 0$,is the maximum spectrum spread over the subcarriers. Hence , we can finally write Y_k as

$$Y_k = (\bar{F}_{0,k} - D)d_k + \sum_{l=-\Delta'}^{\Delta'} Q_{l,k}, \quad \ldots\ldots. \quad (14)$$

$$\bar{T}_1^{(l)}(m,n) = \frac{1}{N}\sum_{q=0}^{N-1}\sum_{p=0}^{q} f_l^{(k+1)}(L_0 - p)e^{j2\pi\frac{mp}{N}} e^{j2\pi\frac{(n-m)q}{N}},$$

Where $Q_{l,k} = -T^{(l)}d_{k+1} + \bar{T}_1^{(l)}E_{-L}d_{k+l}^-$, wit $\times e^{j2\pi\frac{(n-m)q}{N}}$,

$$\bar{T}_u^{(l)}(m,n) = \frac{1}{N}\sum_{q=0}^{N-1}\sum_{p=0}^{q} f_l^{(k+1)}(L_0 - p)e^{j2\pi\frac{mp}{N}} e^{j2\pi\frac{(n-m)q}{N}},$$

And

$$T^{(1)} = \begin{cases} \bar{T}_u^{(0)}E_{-L} + \bar{T}^{(0)}E_L - D \\ \bar{T}_u^{(l)}E_{-L} + \bar{T}_1^{(l)}E_L - \bar{F}_{l,k}, \end{cases}$$

for $l = 0 and l \neq 0$ …… (15)

$\bar{F}_{l,k}$ is a diagonal matrix with entries given by

$$\bar{F}_{l,k}(n,n) = \sum_{p=-\frac{N}{2}}^{\frac{N}{2}-1} f_l^{(k+l)}(p)e^{-j2\pi\frac{np}{N}},$$

Finally , for uncorrelated Zero-mean modulation symbols of equal variance, the SIR k ,n at the k th sub carrier and time index n, is given by

$$SIR_{k,n} = \frac{|\bar{F}_{0.k}(n,n) - D(n,n)|^2}{\sigma_I^2(k,n)}, , , , , , , n \in \Omega^{(k)}, \quad (16)$$

Where $\sigma_I^2(k,n) =$

$$\sum_{l=-\Delta'}^{\Delta'}\sum_{r\in\Omega^{(k+1)}} |T^{(l)}(n,r)|^2 + |\bar{T}_u^{(l)}(n,r)|^2 + |\bar{T}_1^{(l)}(n,r)|^2 .$$

By the analogy with the definition 0f SNR,we consider the equivalent SIR (SIR eq) that provides the same SER floor as the one caused by all the considered SIR k ,n. The values of SIR eq for some combinations of L and N arefor both considered filters.

To avoid these drawbacks, filter-bank multicarrier (FBMC) was proposed as an alternative approach to OFDM. In FBMC, there is no need to insert any guard interval. Furthermore, it uses a frequency well-localized pulse shaping; hence, it provides a higher spectral efficiency. In the literature we find several FBMC systems based on different structure. In particular, we have focused on the Saltsburg's scheme namely OFDM/OQAM. Saltzberg that by introducing a shift of half the symbol period between the in-phase and quadrature components of QAM symbols, it is possible to achieve a baud-rate spacing between adjacent subcarrier channels and still recover the information symbol free of inter symbol interference (ISI) and inter carrier interference (ICI). Thus, each subcarrier is modulated with an offset QAM (OQAM) and the orthogonality conditions are considered only in the real field. Indeed, the data at the receiver side is carried only by the real (or imaginary) components of the signal, and the imaginary (or real) parts appear as interference terms. An efficient discrete Fourier transform (DFT) implementation of this modulation method has been proposed by Hirosaki. In recent years, FBMC has attracted a lot of interest and many equalization and synchronization methods have been developed for this

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modulation. However, most of these works are related to single-input single-output (SISO) systems.

4. Simulation results

A. Performance of FFT-FBMC using PHYDYAS and IOTA prototype filter with MIMO (2×2) spatial multiplexing and QPSK modulation in Ped-A channel.

For both IOTA and PHYDYAS filters, we observe clearly that the BER degradation depends strongly on L due to the BER floor effect caused by the insufficiency of the CP.

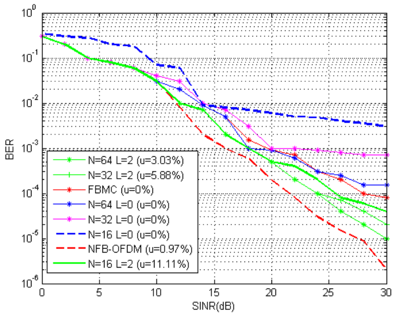

Fig. 6. Performance of FFT-FBMC using PHYDAS prototype filter with spatial multiplexing and QPSK modulation in PED-A channel.

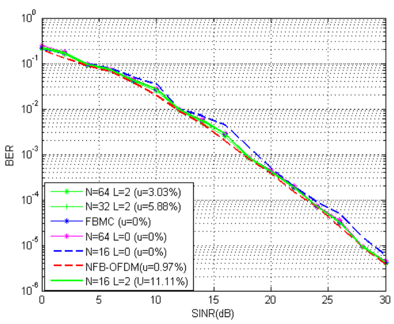

Fig. 7. Performance of FFT-FBMC using IOTA prototype filter alamouti coding scheme and QPSK modulation in PED-A channel.

5. Conclusion

In this paper, we have proposed a new FBMC scheme (called FFT-FBMC). In order to get rid of the intrinsic Interference which is an issue when we combine the FBMC with some MIMO techniques such as SM-MLD and Alamouti coding. The FFT-FBMC system contains in execution an IDFT and DFT on each subcarrier, correspondingly, at the TX and RX sides injecting also a CP as in the conventional OFDM. This makes FFT-FBMC more computationally complex than FBMC. The transmission is applied in direction to segregate the end-to-end subcarriers. In this way, the equivalent system became framed as OFDM, and all MIMO techniques can be applied in a direct manner. We have projected to diminish the CP and calculate the corresponding performance degradation. We tested the projected scheme with two MIMO techniques: (2×2) SM-MLD and (2×1) Alamouti coding, and also with two values of the CP L = 2 and L = 0. Simulation results showed that we can almost obtain the same performance as OFDM in some configurations. However, FFTFBMC remains somewhat outperformed by OFDM for the residual interference.

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