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Analysis of Filter Bank Multi-Carrier system for 5G communications

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Abstract

The FBMC now days preferred for 5th Generation communication system. In this paper a detail analysis on Filter bank multi-carrier system for different cases. In FBMC that represents the transmitted data through IFFT available spectral bandwidth into sub-bands. The digital frequency response of the filter simulates for 5G communications with better response.

Index Terms: FBMC, 5G, OFDM, MIMO

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FBMC works on the principle of the OFDM. FBMC modulation design with principle OQAM procure high data transmission speed [1]. OFDM is an attractive implementation in broadband systems.

- Orthogonally of sub-carriers
- Low complex for generation of transmitted signal through IFFT& Receive signal through FFT.
- Available wide spectral bandwidth into several narrow sub-bands
- Received signal must be synchronized at receiver

Filters are preferred mostly Hamming window, FBMC and Rectangular window. In the rectangular window each subcarrier is having a bandwidth of $\left[\frac{-B}{2}, \frac{B}{2}\right]$. Filter bank designed with very small side lobe. Much sharper beam width produces better spectral sharper spectra [2]. FBMC implementation for multiple access cellular scenarios, cognitive radio applications and broadband data transmission over unshielded wires. FBMC has the potential to fulfill the requirements, concepts and the now the research in FBMC. The physical layer of FBMC has high spectrum resolution & provides independent sub-channel with enriched data rates. The scheme OFDM is a block of processing technique, which lacks flexibility & poor spectral resolution. A multicarrier technique that approaches that capacity limits in the communications.

2. System Model

2.1.System Considerations

FBMC with discrete domain for baseband as follows.

a) Transmitter approach
b) Receiver approach

Power spectral density of FBMC transmit signal is to highlight the low out-of-band leakage. The transmit signal is defined as

$$S_k(t) = \sum_n S_k(n)\, \delta(t - nT) \tag{1}$$

Where$S_k(n)$ are the sub-carriers data symbols. K is the sub-carrier index &T is the symbol time spacing
In OFDM the pulse $P_t(t)$ is a rectangular pulse of width T and height one. The receiver prototype filter $P_r(t)$ also rectangular pulse height unity [3]. However, the width reduced to $T_{FFT} < T$.   Where $T_{FFT} = \frac{N}{B} = \frac{1}{B_s}$. Where B_s is the frequency spacing b/w sub-carriers.T_{FFT} is the actual duration of the OFDM symbol.

FBMC systems that are designed to maximize bandwidth efficiency $T = T_{FFT} = \frac{1}{B}$. In OFDM transmit time offset is T and OFDM-OQAM transmitted time offset $\frac{T}{2}$. Time–Frequency phase space lattice representation with grid transmits analysis [4].

2.2. MMSE equalization of an FBMC system

The MMSE equalizations are classified into

- Linear MMSE
- Adaptive Linear MMSE

In linear MMSE Equalization of FBMC system, the optimization problem is

$$w_{k,MMSE} = \arg\{\min\{E[|a_k(m) - a_k(m - v)^2|\}$$ (2)

v is the equalization delay.

$$y_k[n] = [y_k[n], y_k[n-1], y_k[n-2], y_k[n-3], \dots \dots y_k[n-N_1]]^T$$ (3)

The FBMC system is given by

$$r(k) = \sum_{l=0}^{n-1} h(l)s(k - l) + n(k)$$ (4)

$$r_{u,v} = \sum_{k=-\infty}^{+\infty} r(k)g_{u,v}^*(k)$$ (5)

$$s(k) = \sum_{n=-\infty}^{\infty} \sum_{m=0}^{M-1} a_{m,n} \, g_{m,n}(k)$$ (6)

$$r(k) = \sum_{l=0}^{n-1} h(l) \sum_{n=-\infty}^{\infty} \sum_{n=-\infty}^{M-1} a_{m,n} g_{m,n}(k - l)$$ (7)

$$g_{m,n}(k) = p(k - nm)e^{j\frac{2\pi}{N}mk}e^{j\emptyset_{m,n}}$$ (8)

2.3. FBMC frequency selective channel

Now consider for frequency selective channel is given by

$$r_{u,v} = \sum_{k=-\infty}^{\infty} r(k)g_{u,v}^*(k) = \sum_{k=-\infty}^{\infty} \{\sum_{l=0}^{n-1} h(l)s(k-l) + n(k)\}g_{u,v}^*(k) =$$
$$\sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} h(l)s(k-l)g_{u,v}^*(k) + \sum_{k=-\infty}^{\infty} n(k)g_{u,v}^*(k) \tag{9}$$

The above equation divided into two terms i.e. I term and II terms.
Where the I term is given by

$$\boldsymbol{I\ term} = \sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} h(l)s(k-l)g_{u,v}^*(k) = \sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} h(l) \sum_{n=-\infty}^{\infty} \sum_{m=0}^{N-1} a_{m,n}\, g_{m,n}(k-l)\, g_{u,v}^*(k)$$

$$= \sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} h(l) \sum_{n=-\infty}^{\infty} \sum_{m=0}^{N-1} a_{m,n}\, p(k-nm-l)e^{j\frac{2\pi}{N}m(k-l)}e^{j\emptyset_{m,n}}(k-l)\, g_{u,v}^*(k)$$

$$= \sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} h(l) \sum_{n=-\infty}^{\infty} \sum_{m=0}^{N-1} a_{m,n}\, p(k-nm)e^{j\frac{2\pi}{N}mk}e^{-j\frac{2\pi}{N}ml}\, e^{j\frac{\pi}{2}(m+n)}p(k$$
$$- vM)e^{-j\frac{2\pi}{N}uk}e^{-j\frac{\pi}{2}(u+v)}$$

$$= \sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} \sum_{n=-\infty}^{\infty} \sum_{m=0}^{N-1} h(l)e^{-j\frac{2\pi}{N}ml}a_{m,n}\, p(k-nm)e^{j\frac{2\pi}{N}mk}\, p(k$$
$$- vM)e^{-j\frac{2\pi}{N}uk}e^{j\frac{\pi}{2}(m-u+n-v)}$$

$$= \sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} \sum_{n=-\infty}^{\infty} \sum_{m=0}^{N-1} h(l)e^{-j\frac{2\pi}{N}ml}a_{m,n}\, p(k-vM)e^{j\frac{2\pi}{N}k(m-u)}\, e^{j\frac{\pi}{2}(m-u+n-v)}$$

$$\tag{10}$$

Where

$$p(k - nM - l) \cong p(k - nM) \tag{11}$$

$$\sum_{m=0}^{N-1} h(l)e^{-j\frac{2\pi}{N}ml} = H(m) \tag{12}$$

$$\boldsymbol{I\ term} = \sum_{\boldsymbol{k}=-\infty}^{\infty} \sum_{\boldsymbol{l}=\boldsymbol{0}}^{\boldsymbol{n-1}} \sum_{\boldsymbol{n}=-\infty}^{\infty} \boldsymbol{H(m)\ a_{m,n} p(k - vM)e^{j\frac{2\pi}{N}k(m-u)}\ e^{j\frac{\pi}{2}(m-u+n-v)}}$$
$$= \sum_{\boldsymbol{k}=-\infty}^{\infty} \sum_{l=0}^{n-1} \sum_{n=-\infty}^{\infty} H(m)\ a_{m,n}\xi_{m,n}^{uv} \tag{13}$$

$$\xi_{m,n}^{uv} = p(k - vM)\ e^{j\frac{2\pi}{N}k(m-u)} e^{j\frac{\pi}{2}(m-u+n-v)} \tag{14}$$

$$II\ term = \sum_{k=-\infty}^{\infty} n(k)g_{u,v}^*(k)$$

Then include I term and II term the equation reduces to following expression.
Therefore

$$r_{u,v} = \sum_{k=-\infty}^{\infty} \sum_{l=0}^{n-1} \sum_{n=-\infty}^{\infty} H(m)\ a_{m,n}\xi_{m,n}^{uv} + \sum_{k=-\infty}^{\infty} n(k)g_{u,v}^*(k) \tag{15}$$

$$\sum_{k=-\infty}^{\infty} n(k)g_{u,v}^*(k) = \eta_{u,v} = intrinstic\ impedance \tag{16}$$

$$r_{u,v} = \sum_{\boldsymbol{k}=-\infty}^{\infty} \sum_{l=0}^{n-1} \sum_{n=-\infty}^{\infty} H(m)\ a_{m,n}\xi_{m,n}^{uv} + \eta_{u,v} =$$
$$H(u)\ a_{u,v}\xi_{u,v}^{uv} + \sum_{\substack{\boldsymbol{n}=-\infty \\ \boldsymbol{n\neq v}}}^{\infty} \sum_{\substack{m=0 \\ m\neq u}}^{N-1} H(m)\ a_{m,n}\xi_{m,n}^{uv} + \eta_{u,v} \tag{17}$$

If $m = u$ and $n = v$ then $H(m) \leftrightarrow H(u)$
Real $a_{m,n} = a_{u,v}$

Case(i) for ideal case:

$$h(l) = \delta(l), H(m) = 1 \tag{18}$$

$$r_{u,v} = H(u)\, a_{u,v}\xi_{u,v}^{uv} + \sum_{\substack{n=-\infty \\ n\neq v}}^{\infty} \sum_{\substack{m=0 \\ m\neq u}}^{N-1} H(m)\, a_{m,n}\xi_{m,n}^{uv} + \eta_{u,v}$$

$$= 1.a_{u,v}\xi_{u,v}^{uv} + \sum_{\substack{n=-\infty \\ n\neq v}}^{\infty} \sum_{\substack{m=0 \\ m\neq u}}^{N-1} H(m)\, a_{m,n}\xi_{m,n}^{uv} + \eta_{u,v} \tag{19}$$

$$re\{r_{u,v}\} = re\left\{ 1.a_{u,v}\xi_{u,v}^{uv} + \sum_{\substack{n=-\infty \\ n\neq v}}^{\infty} \sum_{\substack{m=0 \\ m\neq u}}^{N-1} H(m)\, a_{m,n}\xi_{m,n}^{uv} + \eta_{u,v} \right\} = a_{u,v}.1. + \eta_{u,v} \tag{20}$$

So internal symbol interference, Inter Sub-carrier Interference

Case (ii)

$$r_{u,v} = H(u)\left\{ a_{u,v}\xi_{u,v}^{uv} + \sum_{\substack{n=-\infty \\ n\neq v}}^{\infty} \sum_{\substack{m=0 \\ m\neq u}}^{N-1} \frac{H(m)}{H(u)}\, a_{m,n}\xi_{m,n}^{uv} \right\} + \eta_{u,v} \tag{21}$$

The term is considered as Intrinsic Impedance.

$$\xi_{u,v}^{uv} \cong 1, \text{Intrinsic Impedance} = \sum_{\substack{n=-\infty \\ n\neq v}}^{\infty} \sum_{\substack{m=0 \\ m\neq u}}^{N-1} \frac{H(m)}{H(u)}\, a_{m,n}\xi_{m,n}^{uv} \tag{22}$$

Where $(m, n) \in \Omega(u, v)$. Then

$$r_{u,v} = H(u)\left\{ a_{u,v}.1 + \sum_{\substack{(m,n)\in\Omega(u,v)}}^{N-1} \frac{H(m)}{H(u)}\, a_{m,n}\xi_{m,n}^{uv} \right\} + \eta_{u,v} \cong$$

$$H(u)\left\{ a_{u,v} \sum_{(m,n)\in\Omega(u,v)}^{N-1} a_{m,n}\xi_{m,n}^{uv} \right\} + \eta_{u,v} \approx H(u)\left\{ a_{u,v} + \sum_{(m,n)\in\Omega(u,v)}^{N-1} a_{m,n}\xi_{m,n}^{uv} \right\} + \eta_{u,v} \tag{23}$$

$$Re\left\{ \frac{r_{u,v}}{H(u)} \right\} \approx a_{u,v} + Re\left\{ \frac{\eta_{u,v}}{H(u)} \right\} \tag{24}$$

By using OFDM prototype filter the undesirable properties of OFDM arise due to the rectangular impulse prototype filters. That leads to Sinc spectra in the frequency domain [5,6]. Hence response suffers from the large side lobes in the frequency domain. FBMC the successive data symbols overlap. FBMC systems are designed to maximize bandwidth efficiency [7,8]. Intrinsic Impedance is a disadvantage of the FBMC system.

2.4. MIMO based Frequency selective channel FBMC

Consider the MIMO frequency selective channel

$$\tilde{r}(k) = \sum_{t=1}^{N_t} \sum_{l=0}^{L_h-1} h_{rt}(l)\, s_t(k-l) + \eta_r(k) \tag{25}$$

The decoded signal is

$$\tilde{r}_{r,u,v} = g_{u,v}^*(k) = \sum_{k=-\infty}^{\infty} \tilde{r}(k) g_{u,v}^*(k) = \sum_{k=-\infty}^{\infty} \{\sum_{t=1}^{N_t} \sum_{l=0}^{L_h-1} h_{rt}(l)\, s_t(k-l) + \eta_r(k)\}\ g_{u,v}^*(k)$$
$$= \sum_{k=-\infty}^{\infty} \sum_{t=1}^{N_t} \sum_{l=0}^{L_h-1} h_{rt}(l)\, s_t(k-l)\, g_{u,v}^*(k) + \sum_{k=-\infty}^{\infty}\ g_{u,v}^*(k)\, \eta_r(k) \tag{26}$$

Where $s_t(k-l) \rightarrow symbol\ stream\ transmitted\ antenna\ 't'$
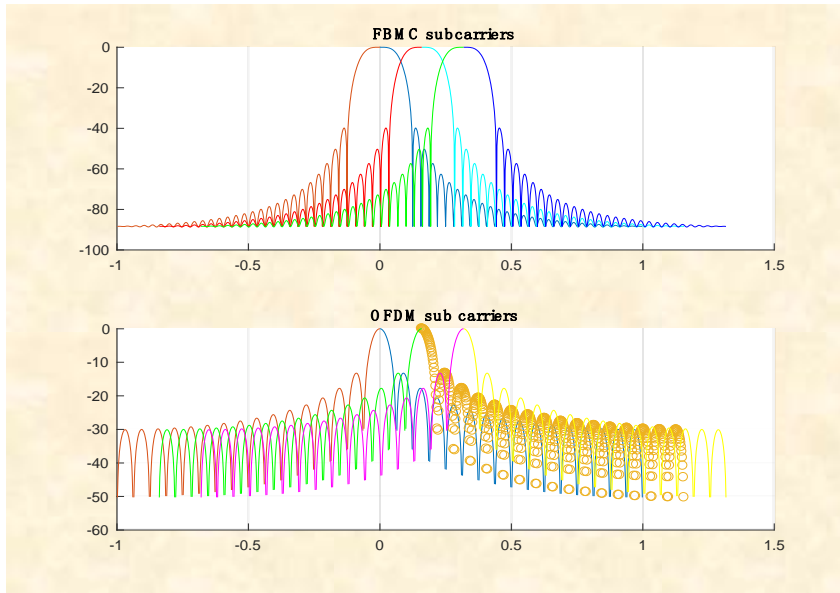
3. Simulation Results
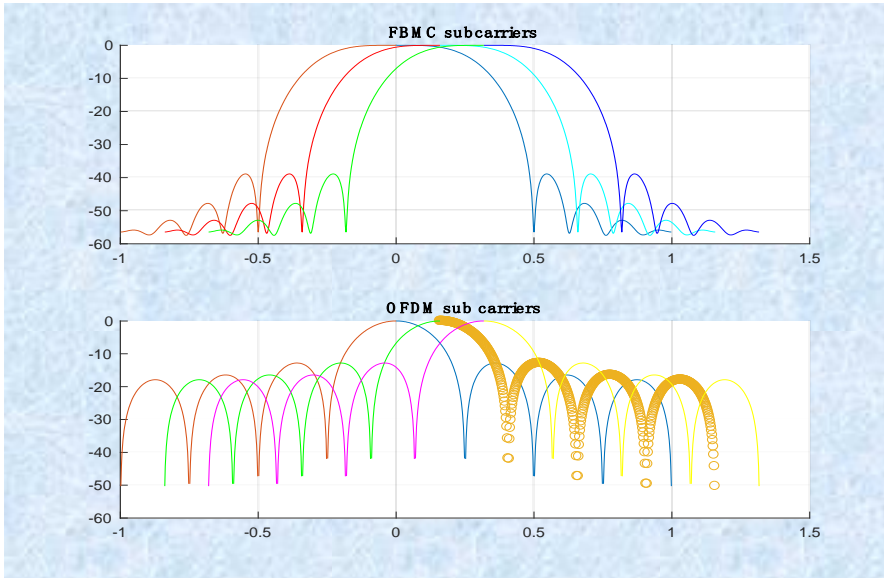
Fig.1. When K=2, M=8

Fig.2.When K=2, M=32

FBMC vs OFDM

In above Fig 1 represents that the simulation response for M=8 the number of sub-channels 8, the overlapping factor K= 2, the prototype filter length k*M-1i.e.15, with the filter coefficients1, sqrt (2)/2 [9,10]. In the a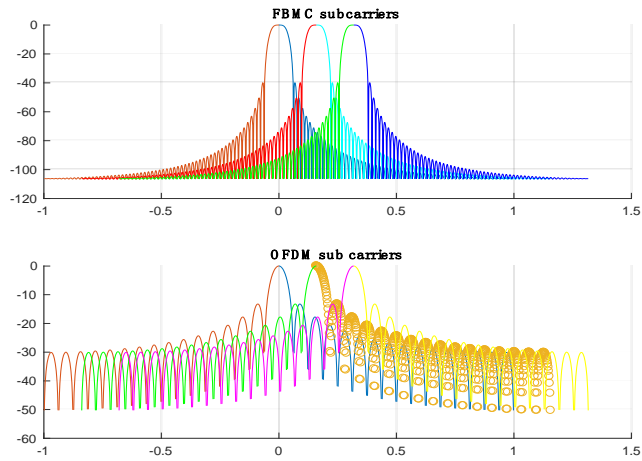bove Fig2 represents that the simulation response for M=32 the number of sub-channels 32, the overlapping factor K= 2, the prototype filter length k*M-1i.e. 63 with the Filter coefficients1, sqrt (2)/2 [11,12].

Fig.3. When K=4, M=32
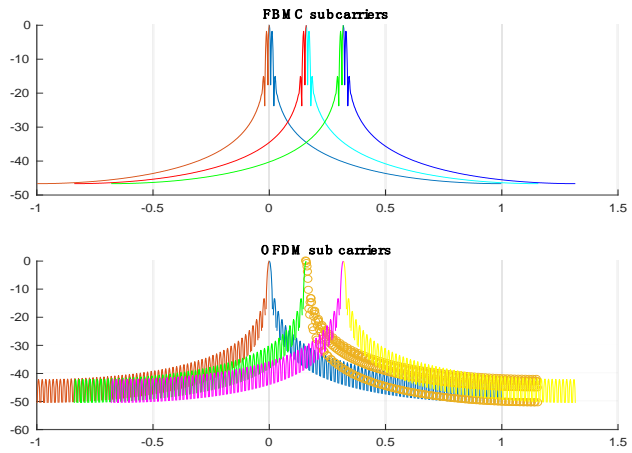

Fig.4. When K=4, M=64

In above Fig3 represents that the simulation response for M=32 the number of sub channels 32, the overlapping factor K= 4, the prototype filter length k*M-1i.e. 63with the filter coefficients 1,0.97195, sqrt(2)/2, 0.235146 [12]. In above Fig4 represents that the simulation response for M=64 the number of sub-channels 32, the overlapping factor K= 4, the prototype filter length k*M-1i.e. 63 with the filter coefficients 1, 0.97195, sqrt (2)/2, 0.235146. The simulation results represent the frequency response of the digital filter. N point frequency vector W in radians/ sample of the filter.
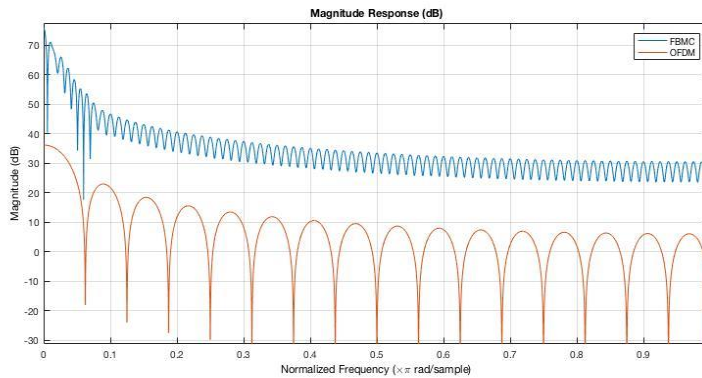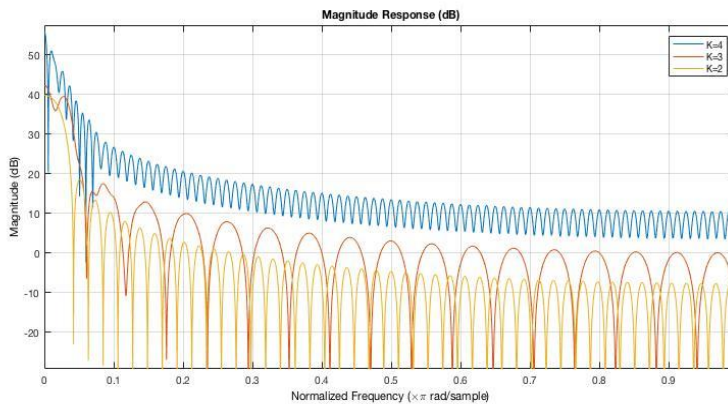

Fig.5.a. FBMC vs OFDM magnitude response

Fig.5.b.Over lapping K=4,K=3,K=2

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The FBMC now days preferred for 5th Generation communication system. In this paper a detailed analysis of the Filter bank multi-carrier system for frequency selective channel and frequency based channels. In FBMC that represents the transmitted data through IFFT available spectral bandwidth into sub-bands.

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