Channel Performance Estimation Using Filter Bank Multi-Carrier Method

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Abstract: In this paper, we compare two multi-carrier techniques for future generation mobile communications are orthogonal frequency Division Multiplexing (OFDM) and Filter Bank Multi-carrier (FBMC).OFDM is the best suitable for fourth generation mobile communications .Due to cyclic-prefix (CP) and wide frequency guards OFDM is inefficient. In this context, a novel multicarrier modulation FBMC used for forthcoming mobile communications. To get the perfect reconstruction and sub-band orthogonality cosine modulated filter banks are used in perfect reconstruction filter bank multicarrier (PR -FBMC), which is not be optimal for communication outlook. So we proposed imperfect reconstruction FBMC (iPR-FBMC) for non-orthogonal transmission. Observe the computational complexity between FBMC and OFDM .The results reveal the achievable rate and bit error rate (BER) performance of iPR-FBMC better compared to PR –FBMC and OFDM in different channels like additive white Gaussian noise channel (AWGN) and highly frequency selective channels for different no of sub-band carriers and length of multipath channels.

Index Terms: Multi-Carrier, OFDM, FBMC, prototype filter design, BER, complexity, iPR-FBMC.

I. Introduction

Transmission of large data over the number of band of sub-carriers simultaneously in wireless communication systems used using multi-carrier modulation (MCM) techniques is used. MCM techniques are orthogonal frequency Division Multiplexing (OFDM) and Filter Bank Multi-carrier (FBMC) for mobile communications. In wired or wireless communication from past two decades OFDM is most successful multicarrier technique. The high data rate stream is split into number of lower data streams and each segment is transmitted through a different carrier signals, however all subcarriers are orthogonal to each other. OFDM is best suitable to fourth generation cellular communication and is good choice to point-to-point communications i.e base station to mobile node and vice versa. It requires less complexity and achieve more bandwidth efficiency. Increase the out of band emission results sharp truncation of the signal. Orthogonal frequency division multiple access (OFDMA) orthogonal frequency Division Multiplexing (OFDM) and Filter Bank Multi-carrier (FBMC) used for uplink multi-user communications requires rigorous time and frequency synchronization. However, with the increasing the no of users and devices enlightened spectrum utilization at low cost drawbacks of OFDM in the presence of cyclic prefix (CP), which leads to spectrum efficiency denied. It is more carrier frequency offset (CFO) and drifts than single carrier system. High peak to average power ratio is required brings disadvantage like reduce efficiency of RF power amplifiers and having large dynamic range of amplifiers necessary, in practical system before transmission OFDM signal is passed through a power amplifier that is always peak power is limited. In latest research to overcome the problems of OFDM replaces with Filter Bank Multi-carrier (FBMC) to next generation mobile communications.

The new waveform generation [1] of multi-carrier modulation Filter Bank Multi-carrier (FBMC) is most promising one. It is having filter banks to the OFDM system and removes the cyclic prefix (CP). Therefore, FBMC is an evolution of OFDM. It vulnerable to ISI(inter symbol interference), ICI(inter carrier interference) due to the mitigation techniques of filter banks and equalization techniques including single and multi-tap equalizers with and without cross sub-band processing [2]. FBMC is different from OFDM, adopts a bank of frequency well localized filters, are synthesis filter bank (SFB) [3] at the transmitter side and analysis filter bank (AFB) at the receiver side. These banks are adjusting the non-adjacent sub-bands almost perfectly in frequency domain. To improves mobility support and demonstrate efficient spectrum orthogonal frequency division multiplexing with offset QAM [10] (OFDM/QAM) is preferred.

Orthogonality between the sub-carriers established by a design real valued cosine modulated low pass prototype filter from analysis and synthesis filter banks. Perfect reconstruction (PR) and nearly perfect reconstruction NPR) is in literature (4), based on audio and image signal processing signal detection performed in different channels like additive white Gaussian noise channel and frequency selective channel. Channel distortion destroys the orthogonality to restore that special type of equalization techniques required. In this paper, we prefer imperfect reconstruction FBMC (iPR-FBMC) for getting rid of sub-band orthogonality in current filter banks by using simple signal processing algorithms with less complexity. iPR-FBMC has been proposed for uplink transmission and for symbol detection, it has better performance than the current available FBMC [5] with PR-FBMC [11]and gives best results than OFDM.

This paper organized as follows. Section-II reviews existing PR-FBMC and proposes iPR-FBMC with symbol detection. Section-III performance analysis, section-IV simulation results, and section-V conclusions. Some notations are defined here; bold symbol X denotes a matrix. * and $\otimes$ denotes convolution and cyclic convolution, Q[x] denotes hard decision of a modulated symbol, $\wedge$ denotes a diagonal matrix whose K^{th} main diagonal entry.

II. PR-FBMC and iPR-FBMC SYSTEM DESCRIPTION:

The transceiver schemes of PR-FBMC andiPR-FBMC with M sub-bands is shown in Fig-1. The number of simultaneous users ‘k’ ($k \leq M$).The orthogonal frequency division multiplexing with offset QAM (OFDM/QAM) critically damped system. For implementation of mapping that is after serial to parallel convertor, Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM) etc…methods are preferred. We opted QAM to get better results compared to remaining modulation techniques. In PR-FBMC, the modulator output is directly given to synthesis filter bank of interpolation factor L. the L is depends on the no of sub-bands (M). For PR-FBMC the L value is half of the number of sub-bands where as in iPR-FBMC (L=M/2), it is equal to number of sub-bands (L=M). No guard bands are required in these two methods where as in OFDM required cyclic prefix, so its spectral efficiency improved. The input data stream $b_m(i)$, m= 1,2,3……M, gm(l) and fm(l) are derived from cosine modulated filter bank.The perfect reconstruction (PR) means that input and output relations of analysis and synthesis systems are given by r(n)=b(n-k). Filter tap indices l=0,1,2….,N_{f-1} ,the filter response depends on number of sub-bands(M) and filter length (N_f).

$G_m(l)=f_p(l)\exp(j\frac{(2*\pi)}{M}\left(m-\frac{1}{2}\right)(l+\frac{(\frac{M}{2}+1)}{2}))$ ……..1(a)

$f_m(l)=g_m^*(N_f-1-l)$ ………1(b)

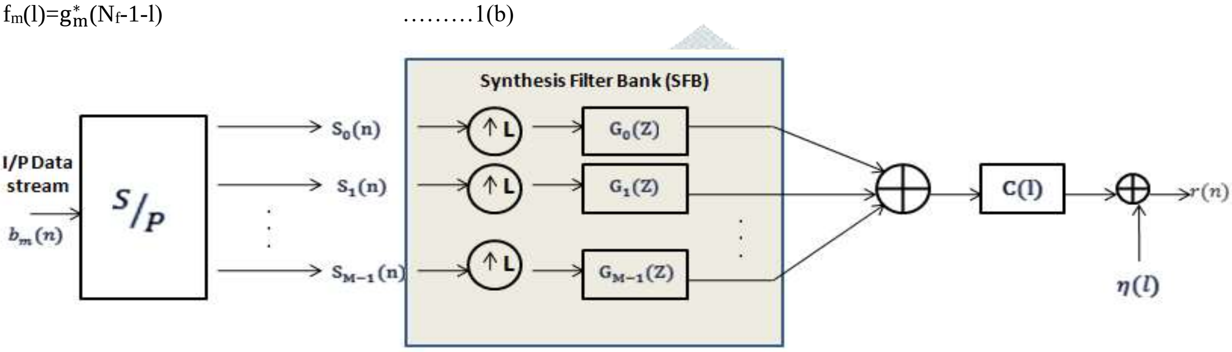

Fig 1: Transmitter diagram of PR-FBMC $S_m(n)$ is QAM modulated (L=M/2) and Proposed iPR-FBMC is QAM modulated and (L=M)

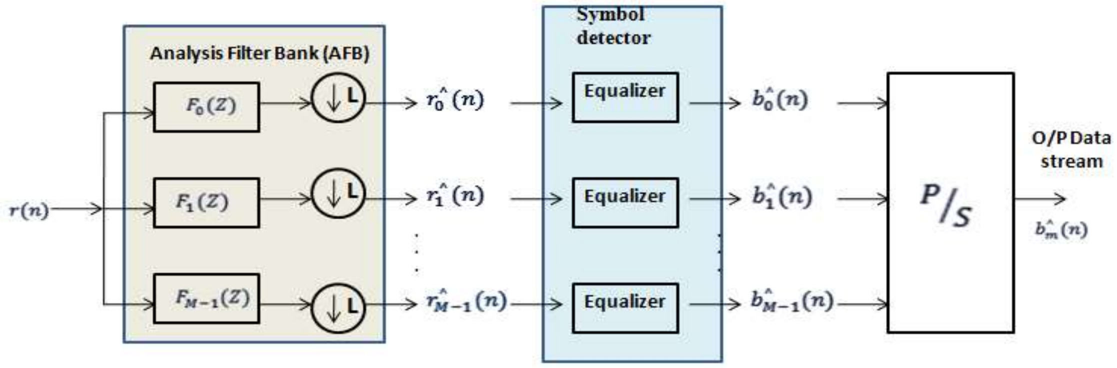

Fig 2: Receiver diagram of PR-FBMC - $S_m(n)$ is QAM modulated (L=M/2) and Proposed iPR-FBMC is QAM modulated and (L=M)

At the transmitter side, the input data $b_m(i)$,m=1,2,3……M of all sub-bands are given to serial to parallel convertor and output is mapped to synthesis filter bank (SFB) with interpolation factor(L), $g_m(l)$,m=1,2,3…M are transmitted through specific channels like additive white $r_m(l)$. At the receiver side, the received signal $\{r(n)\}_{l=0}$ M sub-bands signals $\{s_m(n)\}_{n=0.}$ Analysis filter bank (AFB) having decimation factor equal to no of sub-band (M=L).The symbol detector and hard decision Q[x] are to detect the original signal.

Equalization (or) symbol detection algorithm:

Step 1: $\{s_m(n)\}^{M-1}_{m=0}$ m,j=1,2……M, No and T ,the total number of iterations

Step 2:

i. LMMSE(Liner Minimum Mean Squarer Error) equalizers are designed for different sub-bands m=1,2…..M
ii. Set hard decision $b_m(n)=0$
iii. Set t⟶1

Step 3: while t ≤T do for every m=1,2,3….M

i. Interference estimation:

$$I_m^{\sim}(n)= S_{m,m-1}(n)*b_{m-1}^{\sim}(n) + S_{m,m+1}(n)*b_{m+1}^{\sim}(n);$$

ii. Interference cancellation:

$r_m^{\sim}$(n) = r_m(n) - $I_m^{\sim}$ (n)

iii. Equalization:

$b_m^{\sim}$(n) = v_m(n)* $I_m^{\sim}$ (n)

iv. Hard decision:

$b_m^{\sim}$(n) = Q[$b_m^{\sim}$(n)]

end for

t ⟵ t+1

end while

Step 4: Output:$b_m^{\sim}$(n) for all m,n.

III. Performance analysis:

In this section achievable rate and signal to noise ratio(SNR) for various multicarrier systems; perfect reconstruction filter bank multicarrier (PR -FBMC), imperfect reconstruction FBMC (iPR-FBMC), orthogonal frequency Division Multiplexing (OFDM) measured in various additive white Gaussian noise and frequency selective channel [6][7]. Receivedsignal $\{r_m(n)\}^{M-1}_{m=0}$m=1,2,3…M to compute the achievable(bits/Hz). AWGN channel:The signal was transmitted through AWGN channel given by

$$r_m(n) = \sum_{j=1}^{M} \mathrm{S_{m,j}(n) * b_j(n) + X_m(n)} \quad ………(2)$$

Where $X_m(n)$ is the m[th] poly phase component of the original noise n(l). The noise $X_m(n)$ zero mean and variance N_0 . Frequency domain of the received signal given by

$$r_m(q) = \sum_{j=1}^{M} \mathrm{S_{m,j}(q) * b_j(q) + X_m(q)} \quad …..…(3)$$

To converting equation (2) and (3) the discrete Fourier transform is used. Singular value μ(k),the average transmitted power P_x given by

$$P_x = \frac{1}{(M*N_d)} \sum_{k=0}^{M_p-1} \mathrm{P(k) * \mu^2(k)} \quad …… (4)$$

The number of non-zero singular values determined by cosine modulated low pass proto type [9] filter. M_p positive singular values and power allocated to K[th] Eigen value then the maximum achievable rate R is

$$R = \frac{M_p}{(M*N_d)} \log_2\left(1 + \frac{(M*N_d*P_x)}{(M_p*N_0)}\right) \quad ……(5)$$

Frequency selective channel:

The channel state information (CSI) is doesn't known at the transmitter, consider unity at the receiver. The maximum achievable rate through FSC is

$$\mathrm{R(c)} = \frac{1}{(M*Nd)} \log_2 det\left(1 + \frac{1}{No} Gc \vee \Lambda \mathrm{vHGcH}\right) \quad …… (6)$$

Λ denotes a diagonal matrix whose K[th]main diagonal entry.

Due to proper signal rotation and power allocation, the received signal to noise ratio can be written as

$$J_F = \mathrm{SNR}\frac{M}{(4*\pi)} \int_{\frac{-\pi}{M}}^{\frac{(3*\pi)}{M}} \left|\mathrm{H(e^{jw})}\right| \mathrm{dw}$$

$$= \mathrm{SNR}\ C^H T_F C$$

T_F is Hermitan matrix of size L_cx L_c

Table 1: Parameters required for simulation

System parameters	Possible values
Modulation	QAM
Data block length N_d	100
Number of sub-bands/subcarriers	8,16
Length of sub-band filter	N_f = 4M
Length of multi-path channel	L_c = 3,12

IV. Simulation results:

Fig 3 : shows the achievable rates of single user iPR-FBMC, PR-FBMC and OFDM for different number of sub-carriers/sub-bands (M).Achievable rates are compared with channel capacity in both AWGN channel and FSC channel for M=16. In channel AWGN, equal power gains among all taps and power is unity. All techniques achieving channel capacity irrespective of M. In frequency selective channel, iPR-FBMC, PR-FBMC are achieving channel capacity for any M but OFDM achieving small values of M.

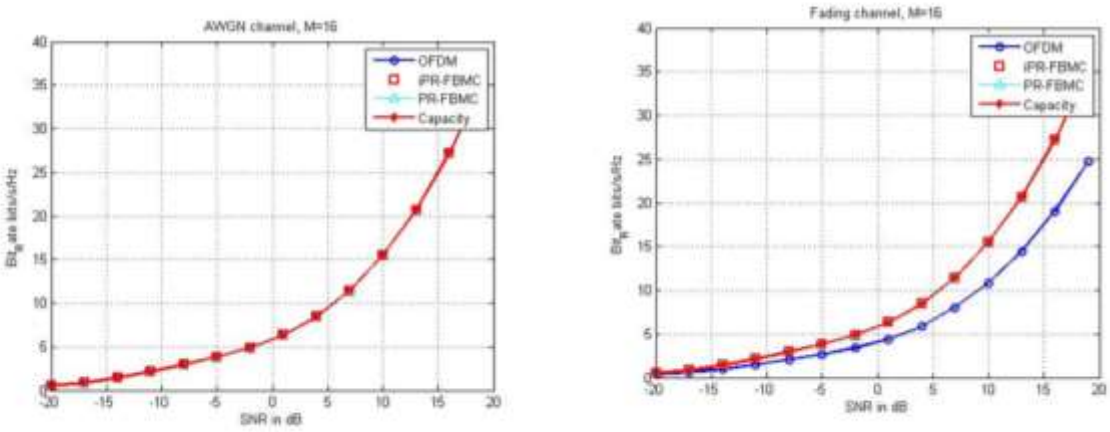

Fig 3: Achievable rate comparison of iPR-FBMC, PR-FBMC, OFDM and channel capacity for M=16 in AWGN and fading channels

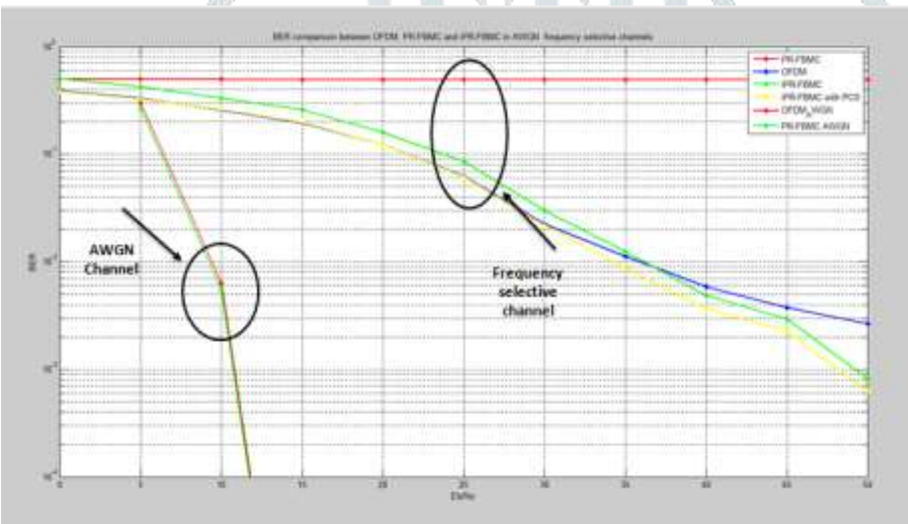

Fig 4: BER comparison between OFDM, iPR-FBMC and PR-FBMC in both AWGN channel and frequency selective channel for M=8, L_c=12.

Figure 4: shows bit error rate (BER) of different techniques for sub-carriers M=8 and N_c =12 in both AWGN and FSC. It gives the iPR-FBMC has less BER as compared to PR-FBMC and even outperforms OFDM, by observing the Table 2. Corresponding E_b/N_0 the bit error rate ismeasured.

For up-link multi user communication, sub-band allocation schemes are localized, interleaved and random allocation. Localized sub-band allocation scheme is practical for PR-FBMC in uplink, interleaved and random allocations are not suitable because it required no of sub-bands. Where as in iPR-FBMC, all schemes [8]are suitable as compared to PR-FBMC not only spectral efficiency improved by eliminating sub-bands but also flexibility of resource management could be improved. Fig5: represents computational complexity increases with rise in number of real multiplications with respect to sub-bands (M).

Table 2: BER V_S E_b/N_0 for AWGN channel and frequency selective channel

E_b/N_0	BER AWGN Channel		BER Frequency Selective Channel		
	OFDM	PR-FBMC	OFDM	PR-FBMC	iPR-FBMC
10	0.00505	0.00505	0.235	0.46	**0.325**
20	0	0	0.1	0.46	**0.145**
35	0	0	0.0073	0.46	**0.0046**

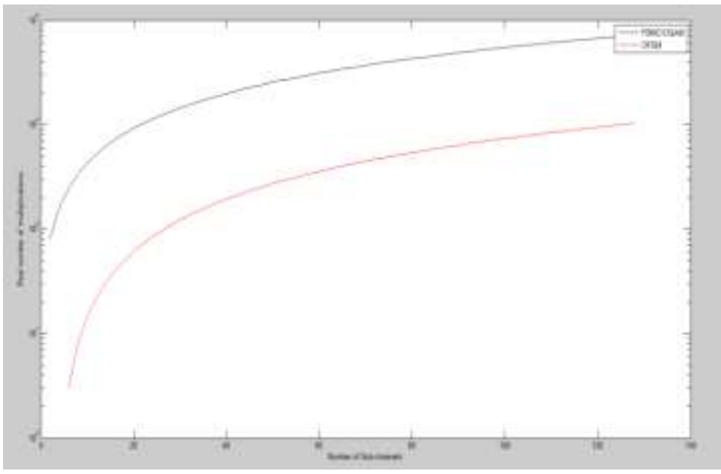

Fig 5: Complexity between OFDM and FBMC

V. Conclusion:

A novel proposed FBMC: imperfect reconstruction Filter Bank Multi-carrier (iPR-FBMC) suitable to fifth generation cellular communication scenarios. iPR-FBMC gives superior bit error rate compared to PR-FBMC and even outperforms to OFDM. It is more priority to symbol detection rather than perfect reconstruction. In implementation and number of multiplications point of view FBMC is complexity than OFDM. Results show that FBMC can achieve more spectral efficiency, channel capacity than OFDM. Further research regarding FBMC is area of MIMO.

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