A Study on the MC-CDMA Using CMFB IIR Filter

Jonghong Shin[1] and Sunbong Jang[2] and Innho Jee[3]
[1]School of Electronics, Electrical and Computer Engineering, Hongik University,
Chochiwon, Chungnam, 339-800, KOREA
Tel. +82-41-860-2596, Fax. + 82-41-865-0460
[2]School of Electronics, Electrical and Computer Engineering, Hongik University,
Chochiwon, Chungnam, 339-800, KOREA
[3]School of Electronics, Electrical and Computer Engineering, Hongik University,
Chochiwon, Chungnam, 339-800, KOREA
e-mail : sigs@won.hongik.ac.kr, sunbj@shinan.hongik.ac.kr, ijee@wow.hongik.ac.kr

Abstract : Because of superior division among sub-channels, DWT MC-CDMA is less interference with neighborhood channel. In our newly proposed multi-carrier CDMA data transmission method, IIR CMFB filter banks sharply divide sub-bands and reduces spectral overlaps among neighboring sub-channels. In experiment result, proposed filter is better ability of sub-band division than FIR filter. Since the proposed cosine modulated filter banks IIR filter having wavelet property is designed to response sharp transition band, the ISI and ICI between neighboring sub-channels can be effectively reduced. And robustness about narrow band interference of CMFB IIR MC-CDMA almost same FIR DWT MC-CDMA.

1. Introduction

Multi-carrier code division multiple access (MC-CDMA) has received much attention owing to its high data transmission, bandwidth efficiency and frequency diversity characteristics. The traditional MC-CDMA combines OFDM with CDMA, the modulation and demodulation can be implemented easily by means of IDFT and DFT operation. In such a system, however, the input data bits are actually truncated by a rectangular window and the envelope of the spectrum takes the form of $\sin(w)/w$ which attenuates slowly. Multi-path fading or synchronization error will cause severe degradation due to inter-subchannel-interference(ICI), inter symbol interference(ISI) and multiple access interference (MAI). Wavelet transform has many attractive properties such as time-frequency localization, orthogonalities. By utilizing these properties, a scheme based on wavelet transform is proposed, which is effective in suppressing interference caused by multi-path fading, ICI and MAI etc. Wavelet filters are generally implemented as finite impulse response(FIR) filters which require a high order for a sharp transition band but are computationally stable. Infinite impulse response(IIR) filters, on the other hand, give superior performance with a better transition region. However they can be computationally unstable unless proper care is taken. In our newly proposed multi-carrier CDMA data transmission method, a perfect reconstruction(PR) IIR cosine modulated filter banks (CMFB) are introduced to take the place of the fast Fourier transform as a purpose to sharply divide sub-bands and to reduce spectral overlaps among neighboring sub-channels. Since the proposed IIR CMFB filter having wavelet property is designed to response sharp transition band, the ISI and ICI between neighboring sub-channels can be effectively reduced.

This work was supported by grant No. (R02-2000-00258) from the Basic program of the Korea Science & Engineering Foundation

2. M-Channel PR IIR CMFB

In the proposed M-channel perfect reconstruction IIR CMFB, the analysis filters $f_k(n)$ and the synthesis filters $g_k(n)$ in a CMFB are obtained by modulation a prototype filter $h(n)$ as follow

$$f_k(n) = h(n)c_{k,n}, \quad g_k(n) = h(n)\,\bar{c}_{k,n}, \quad k = 0, 1, \cdots, M-1 \tag{1}$$

where M is the number of channels. The modulation we shall be using is the extended lapped transform(ELT)[6] given by

$$c_{k,n} = \sqrt{\frac{2}{M}} \cos\left[(2k+1)\frac{\pi}{M}\left(n - \frac{M-1}{2}\right)\right] \tag{2}$$

and $\bar{c}_{k,n}$ is the time reverse of $c_{k,n}$. The PR condition for the biorthogonal CMFB is given by[5]

$$H_k(z)H_{2M-k-1}(z) + H_{M+k}(z)H_{M-k-1}(z) = \beta \cdot z^{-n_k}, \quad k = 0, 1, \cdots, (M/2)-1 \tag{3}$$

where $H_k(z)$ is the type-I polyphase component of the prototype filter $H(z) = \sum_{k=0}^{2M-1} z^{-k} H_k(z^{2M})$. In our IIR CMFB, $H_k(z)$'s are assumed to have the same denominator (i.e., $H_k(z) = N_k(z)/D(z)$ for $k=0,1,\cdots,2M-1$). The PR condition in (3) is then simplified to

$$N_k(z)N_{2M-k-1}(z) + N_{M+k}(z)N_{M-k-1}(z) = \beta \cdot z^{-n_k} D^2(z) \qquad k=0,1,\cdots,(M/2)-1 \tag{4}$$

To ensure that the analysis and synthesis filters be causal, stable all the roots of $D(z)$ shall remain inside the unit circle. In this paper, we considered J. S. Mao's IIR CMFB prototype filter of four-channel.[7] Table 1. show that J. S. Mao proposed Polyphase components.

Table 1. Polyphase components of IIR CMFB

n	$N_0(z)$	$N_1(z)$	$N_2(z)$
0	$-3.12557944544 * 10^{3}$	$-1.60009132266 * 10^{3}$	$-1.83137670080 * 10^{-2}$
1	$7.83542294645 * 10^{-2}$	$1.08716394434 * 10^{-1}$	$1.27933368937 * 10^{-1}$
2	$8.42025828100 * 10^{-2}$	$6.85710216206 * 10^{2}$	$6.01788955552 * 10^{-2}$
3	$2.54074353169 * 10^{2}$	$1.60683328808 * 10^{2}$	$8.01528985062 * 10^{3}$
4	$2.38261702583 * 10^{3}$	$3.70657360370 * 10^{-3}$	$-1.63044851060 * 10^{3}$
n	$N_3(z)$	$N_4(z)$	$N_5(z)$
0	$-1.5806821916 * 10^{-2}$	$-1.04160432697 * 10^{-2}$	$-2.35743639347 * 10^{-3}$
1	$1.41723534957 * 10^{-1}$	$1.42892078030 * 10^{-1}$	$1.32910487827 * 10^{-1}$
2	$5.18833012435 * 10^{-2}$	$4.75007923182 * 10^{-2}$	$4.20699411528 * 10^{-2}$
3	$2.52314605359 * 10^{-3}$	$-4.55708296417 * 10^{-4}$	$-6.51081884329 * 10^{-4}$
4	$-4.7827227430 * 10^{-4}$	$-9.15301949931 * 10^{-4}$	$-3.93238839554 * 10^{-4}$
n	$N_6(z)$	$N_7(z)$	$D(z)$
0	$2.69819929907 * 10^{-2}$	$5.13110294957 * 10^{-2}$	1.000000000000000
1	$1.23549757935 * 10^{-1}$	$1.03607486600 * 10^{-1}$	$4.27901893176 * 10^{-1}$
2	$4.15360157255 * 10^{-2}$	$3.37759268206 * 10^{-2}$	$4.58206764361 * 10^{-2}$
3	$1.31383761921 * 10^{-3}$	$2.83707058171 * 10^{-3}$	
4	$-1.7297799769 * 10^{4}$	$-1.83732232469 * 10^{-4}$	

The magnitude response of analysis filters of a four-channel IIR CMFB designed by the proposed method are shown in Fig 1. The order of $N_k(z)$ and $D(z)$ are, respectively, 4 and 2.

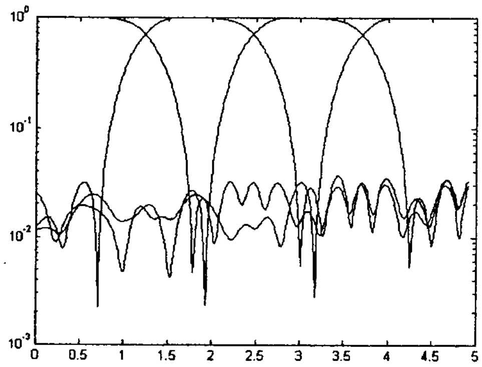

Fig 1. Magnitude response of four-channel IIR CMFB analysis filters

3. System Model and Analysis

In this paper, MC-CDMA system and channel model designed based on proposed model by [1].

A. Transmitter

The transmitter for the kth user is shown Fig 2. where $d_h^{\,k}$ is binary data sequence, and $c_n^{(k)}$ is a spreading sequence.

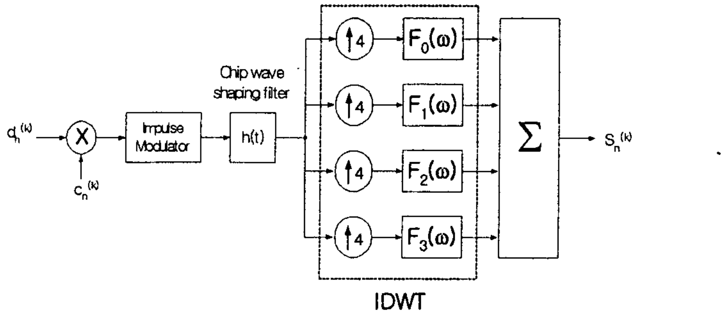

Fig 2. Transmitter for kth user block diagram

The spreading signal modulates an impulse train. After passing through a chip wave-shaping filter, the signal out of the inverse discrete wavelet transform using IIR filters modulates the multiple carrier signals and is transmitted.

B. Receiver

The receiver of the user($k=1$) is shown in Fig 3. where we assume the following characteristics for the chip wave-shaping filter

$X(f) \equiv |H(f)|^2$ satisfies the Nyquist criterion

$$F^{-1}|H(f)|^2 \equiv x(t)$$

and

$$\int_{-\infty}^{\infty} |H(f)|^2 df \equiv 1$$

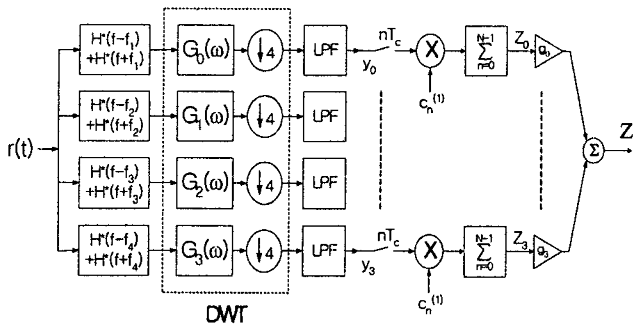

Fig 3. Receiver for the first user block diagram

C. Channel model

The channel model is assumed to be a slowly varying frequency selective Rayleigh channel. Each sub-band of a multi-carrier system has no selectivity and All sub-band are subject to independent fading. The complex lowpass equivalent impulse response of the

ith channel can be written as

$$c_i = \xi_i' \delta(t) \qquad i = 0, 1, \cdots, M \tag{5}$$

where $\{ \xi_i', \ i = 1 \cdots M \}$ are identically independent distribution (i.i.d), zero-mean, complex Gaussian random variables. Under the above assumptions, transfer function of the ith frequency band for the kth user is given by $\xi_{k,i}' = \alpha_{k,i}\, e^{j\beta_{k,i}}$, where $\alpha_{k,i}$ and $\beta_{k,i}$ are respectively, an i.i.d. uniform random variable over $[0, 2\pi)$. Consider the single user case, the conditional signal to noise of a multi-carrier receiver, ρ_m, can be written as

$$\begin{aligned} \rho_m &= N^2 E_c \sum_{i=0}^{M} \frac{\alpha_{1,i}^2}{\alpha_i^2} \\ &= \frac{2NE_c}{\eta_0} \sum_{i=0}^{M} \alpha_{1,i}^2 \\ &= \frac{2MNE_c}{\eta_0} \frac{1}{M} \sum_{i=0}^{M} \alpha_{1,i}^2 \end{aligned} \tag{6}$$

In multi-user case, the conditional signal to noise of a multi-carrier receiver, ρ_m, can be written as

$$\rho_m = N^2 E_c \sum_{i=0}^{M} \frac{\alpha_{1,i}^2}{\frac{(K-1)NE_c}{2}\left(1 - \frac{\alpha}{4}\right) + \frac{N\eta_0}{2}} \tag{7}$$

4. Numerical and simulation results

For experiment, Daubechies FIR filter is extended four-channel single level. Fig 4. show that Single-level M-band filter banks can be constructed this way, using two-band designs.

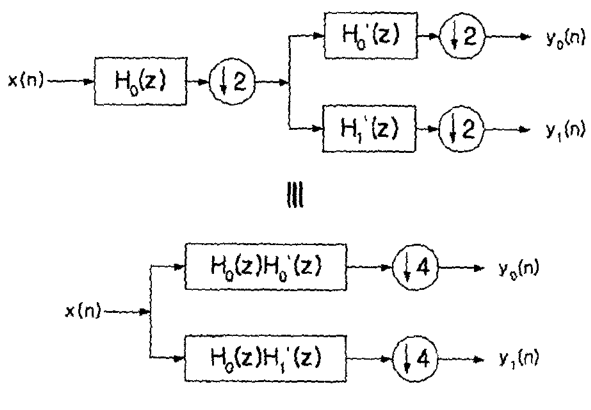

Fig 4. Block diagram for extended Daubechies four-channel

In Fig 5. first experiment is frequency response comparison of Daubechies FIR filter and proposed IIR CMFB filter. IIR CMFB filter frequency response of 48-tap length is more excellent than same length FIR filter in transition area. Although channel 1 and channel 4 are almost same, IIR CMFB, however, superior to Daubechies FIR. Channel 2 and channel 3 are IIR CMFB assuredly superior to Daubechies FIR. Therefore, in same length, secure performance that CMFB IIR MC-CDMA is superior to FIR.

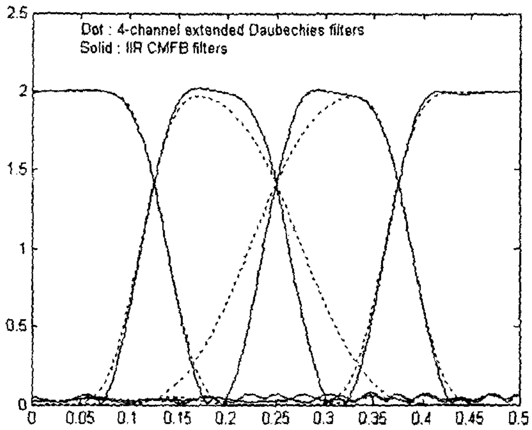

Fig 5. Four-channel filter banks

In second experiment, we measured bit error rate(BER) to test performance of MC-CDMA that use IIR CMFB wavelet transform. Measured BER of FFT MC-CDMA in same condition for comparison. Input data sequences were used random binary sequences and spreading code was used 31 chips Gold sequences. When considered multi-user interference, Fig 6. is experiment result under AWGN channel condition and when 50 users exist. IIR CMFB MC-CDMA has excellent performance more than FIR DWT MC-CDMA. Therefore proposed IIR CMFB filters are better ability of sub-band division.

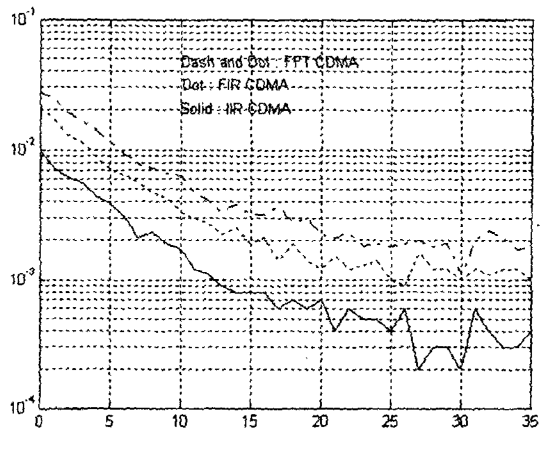

Fig 6. BER test in AWGN and Rayleigh channel, 50 user

Fig 7. is experiment result of when 100 users exist and shows same result such as previous experiment.

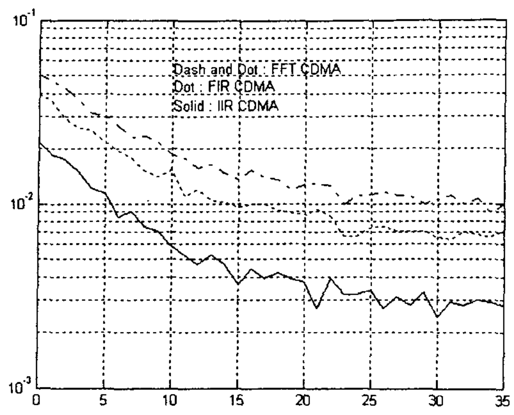

Fig 7. BER test in AWGN
and Rayleigh channel, 100 user

Fig 8. is result of when white Gaussian narrow band interference exists to the 3rd channel of four-channels. This is an experiment that keep orthogonality between sub-channel. JSR is defined as following

$$JSR = \frac{Interference\ Power}{Signal\ Power} = \frac{\eta_J W_J}{\frac{E_b}{T}} \tag{8}$$

η_J is PSD of white Gaussian and W_J is bandwidth of narrow band interference. In this experiment, established bandwidth by $\pi/4$. We fixed JSR by 10dB and found white Gaussian noise variance according to bit energy change. The next time, made interference using this variance and inserted to channel. Although proposed IIR CMFB filter is biorthohonal, in this experiment, BER performances of IIR CMFB MC-CDMA is almost same BER performances of FIR DWT MC-CDMA.

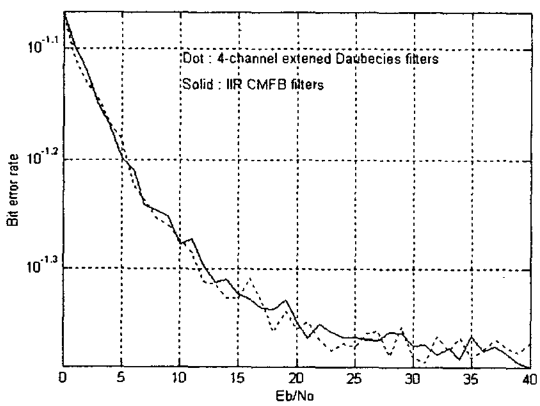

Fig 8. BER test in AWGN
and Rayleigh channel, 50 user, JSR=10dB

5. Conclusion

Because of superior division among sub-channels, DWT MC-CDMA is less interference with neighborhood channels. In our newly proposed multi-carrier CDMA data transmission method, a perfect reconstruction IIR filter bank sharply divides sub-bands and reduces spectral overlaps among neighboring sub-channels. Since the proposed CMFB IIR filter having wavelet property is designed to response sharp transition band, the ISI and ICI between neighboring sub-channels can be effectively reduced. First experiment is frequency response comparison of Daubechies FIR filters and proposed IIR filter. IIR filter frequency response of 48-tap length is more excellent than same length FIR filter in transition area. Therefore, in same length, secure performance that IIR MC-CDMA is superior to FIR. In multi-user experiment, IIR MC-CDMA has superior performance more than FIR DWT MC-CDMA in BER test. As a result, proposed filter is better ability of sub-band division than FIR filter. Narrow band interference test is an experiment that keep orthogonality among sub-channels. Although proposed IIR CMFB filter is biorthohonal, in this experiment, BER performances of IIR CMFB MC-CDMA is almost same BER performances of FIR DWT MC-CDMA. So, need more researching of orthogonal IIR CMFB filter designed and applying to multimedia communication.

6. Reference

[1] Shiro Kondo and Laurence B. Milstein, "Performance of Multicarrier DS CDMA Systems", IEEE Trans. Comm., Vol. 44, No. 2, pp. 238-246, Feb. 1996.

[2] Branislav M. Popovic, "Spreading Sequences for Multicarrier CDMA Systems", IEEE Trans. on Comm., Vol. 47, No 6, June 1999, pp. 918 - 926.

[3] Kenneth Hetling, Michael Medley, Gary Saulnier, and Pankaj Das, "A PR-QMF(Wavelet) Based Spread Spectrum Communications System", 1994 IEEE, pp. 760 - 764.

[4] I. Daubechies, "Orthonormal basis of compactly supported wavelets", Comm. Pure and Appl. Math, XLI:909-996, 1988.

[5] T. Q. Nguyen and P. N. Heller, "Biorthogonal cosine-modulated filter banks", in IEEE Proc. ICASSP 96, vol. 3, May 1996, pp. 1471-1474.

[6] H. S. Malvar, "Extended lapped transforms: Properties, applications, and fast algorithms", IEEE Trans. Signal Processing, vol. 40, pp. 2703-2714, Nov. 1992.

[7] J. S. Mao, S. C. Chan, K. L. Ho, "Theory and Design of a Class of M-Channel IIR Cosine-Modulated Filter Banks", IEEE Signal Processing Letter, vol. 7, No. 2, pp. 38-40, Feb. 2000.