FILTER BANK BASED INTERFERENCE SUPPRESSION FOR FADING CHANNELS

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Abstract

In this paper, we propose a complex-valued unitary filter bank for multicarrier (MC) transmission to suppress the interference introduced by fading channels. The filters of proposed filter bank are orthogonal, have asymmetric frequency responses and are adaptive to different applications. The advantage of the proposed filter bank is that it is more suitable to deal with complex-valued signals and can be optimized towards various objective functions. We show that, in terms of the total interference power over two sample fading channels, the MC systems based on proposed filter banks has superior performance over discrete Fourier transform (DFT) based orthogonal frequency division multiplexing (OFDM) and discrete wavelet multitone (DWMT).

Keywords: *OFDM; ISI; ICI; complex-valued filter bank.*

1. INTRODUCTION

Recently, orthogonal frequency division multiplexing (OFDM) system, which is a special form of multicarrier modulation (MCM), has been paid a lot of attention in various application of high speed wireless digital communication systems. In OFDM systems, modulation filters form a set of orthogonal basis function so that if the distortion in the channel is sufficiently mild (relative to the bandwidth of a subchannel), the data in a subchannel can be demodulated with a negligible small amount of interference from the other subchannels [1]. Discrete Fourier transform (DFT) based OFDM and discrete wavelet multitone (DWMT) are two kinds realizations of OFDM systems. DFT-based OFDM is sensitive to narrow band interference because it has significant spectral overlap between subchannels and the technique called "cyclic prefix" is often employed to reduce this sensitivity with cost of system efficiency. In DWMT system, interchannel interference (ICI) is minimized by well-designed prototype filter [2], while the intersymbol interference (ISI) is not considered and so far only real-valued filter banks are used.

In this paper, we propose a complex-valued unitary filter bank for OFDM system. Unlike to real-valued coefficient filters, complex-valued filters have asymmetric frequency responses and are more suitable to deal with complex-valued signals which are often present in a wireless system. The filters of proposed filter bank are orthogonal, have asymmetric and can be adaptive to different applications. The application adaptability is achieved by introducing free parameters into the coefficients of filter bank by firstly using free parameters to produce the Householder parameters of polyphase component matrices of the filter bank, then generating filter bank with Householder parameters according to Householder factorization algorithm. The values of free parameters can be determined according different objective functions. As an application, we formulate the normalized sum of ICI and ISI power over fading channels, and take the average interference power as objective function to check the performance of proposed filter bank described above. Simulation results show the OFDM system based on proposed complex-valued unitary filter bank can significantly reduce the power of interference compared to DFT-based OFDM and DWMT over two sample fading channels.

2. UNITARY FILTER BANK DESIGN

Figure 1 is the general block diagram of OFDM systems. In OFDM systems, the transmitting filters $[f_0(n), f_1(n), \cdots, f_{M-1}(n)]$ form a set of orthogonal basis functions. To make the filter bank in figure 1 a perfect reconstruction (PR) filter bank, the transmitting filters and receiving filters should satisfy the Biorthogonal property [3]. Unitary filter banks are a

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special class of PR filter banks where the receiving filters are determined by the analysis filters as follows:

$$f_k(n) = h_k^*(-n) \tag{1}$$

There are different realizations for the receiving filter bank $[h_0(n), h_1(n), \cdots, h_{M-1}(n)]$, for example, DFT matrix in DFT-based OFDM and extended orthogonal transform in DWMT. The complex-valued unitary filter bank is used in this paper because of its advantages to process complex-valued signals and its adaptability to different applications.

2.1 Householder Factorization of Polyphase Component Matrices

The class of FIR unitary filter banks has several advantages, they can be completely factorized according to Householder factorization algorithm, are easy to implement and stable [4].

The Householder factorization of polyphase component matrices of transmitting filters $h_0(n)$, $h_1(n), \ldots, h_{M-1}(n)\}$ for complex-valued unitary filter bank can be summarized as following. The z-transform of filter $h_i(n)$, $i = 0,1,\ldots,M-1$ can be formulated in polyphase form as:

$$\mathbf{H}_i(z) = \sum_{k=0}^{M-1} z^{-k} \mathrm{H}_{i,k}(z^M). \tag{2}$$

Define the polyphase component matrices $H(z)$ as follows:

$$(\mathbf{H(z)})_{i,k} = \mathbf{H}_{i,k}(z) \ , \tag{3}$$

if $\mathbf{H}(Z)$ is a unitary matrix, i.e.

$$\mathbf{H}^T(z^{-1})\mathbf{H}(z) = I \, , \tag{4}$$

where I is the unity matrix, then $\mathbf{H}(Z)$ has the Householder factorization

$$\mathbf{H}(z) = \{\prod_{n=1}^{K-1}[I - v_n v_n^H + z^{-1} v_n v_n^H]\}\mathbf{V}_0 \, . \tag{5}$$

K is the McMillan degree of $\mathbf{H}(Z)$, v_n is unit-norm Householder parameters and v_n^H is the transposed conjugation of v_n. $\mathbf{V}_0$ is a $M \times M$ constant unitary matrix and can be selected according to different applications. As a special case, for filter banks associated with M band wavelet transform, $\mathbf{V}_0$ may be generated by assigning one column as a constant vector $\left[\frac{1}{\sqrt{M}}, \frac{1}{\sqrt{M}}, \ldots, \frac{1}{\sqrt{M}}\right]^T$ which corresponds to scaling filter, then add M-1 orthogonal columns to generate wavelet filter vectors [5]-[6] . The M-1 orthogonal columns may be produced via Gram-Schmidt process in $\binom{M-1}{2}$ ways.

2.2 Parameterization of Householder Parameters

The Householder parameters are of unit norm, therefore each Householder parameter in (5), v_n, can be further parameterized as [7]:

$$v_{n,j} = [\prod_{k=0}^{j-1} \sin(\theta_{n,k})]\cos(\theta_{n,j})\exp(j\varphi_{n,j}),$$

when j=0,…,M-2, and

$$v_{n,M-1} = \prod_{k=0}^{M-2} \sin(\theta_{n,k}) \, , \tag{6}$$

i.e., v_n can be determined by $2(M-1)$ angle parameters and therefore if $\mathbf{V}_0$ has been determined, filter bank $\{f_0(n), \ f_1(n), \ldots, f_{M-1}(n)\}$ is determined by 2(K-1)(M-1) angle parameters $\theta_{n,j}$ and $\varphi_{n,j}$, $j = 0,1,\ldots, M-2$, $n = 0,1,\ldots, K-1$. The length of filters $f_i(n)$, $i = 0,1,\ldots,M-1$ is $N = KM$.

2.3 Design Procedure

To calculate all coefficients in (5), constant matrix $\mathbf{V}_0$ and free parameters $\theta_{n,j}$, $\varphi_{n,j}$ in (6) should all be determined. We propose to determine $\mathbf{V}_0$ first according to different applications and then determine the values of free parameters with numerical optimization method towards different objective functions. The non-uniqueness in the generation of $\mathbf{V}_0$ provides flexibility in the design of M-band complex-valued unitary filter bank. In this paper, we propose $\mathbf{V}_0$ to be the $M \times M$ DFT matrix. The conjugate gradient method is used for filter bank optimization. Note that the optimization may fall into a local minimum. Some global optimization methods such as adding random interference and simulated annealing may be used. However, in practice, a local minimum may be satisfactory as well.

3. INTERFERENCE SUPPRESSION BASED ON PROPSED FILTER BANKS

3.1 Calculation of Interference Power

In OFDM system, data are transmitted in blocks, with each block comprising M symbols. The M symbols in a block are transmitted simultaneously with each symbol assigned to a different one of M subchannels. For a given subchannel $m1$, the ISI and ICI introduced to symbol $x_{m1}(i1)$ which transmitted in data block $i1$, can be expressed respectively as [8]:

$$ISI_{m1} = \sum_{\substack{i=-\infty \\ i\neq i1}}^{\infty} \alpha_{m1}(i) x_{m1}(i) \ , \tag{7}$$

$$ICI_{m1} = \sum_{i=-\infty}^{\infty} \sum_{\substack{m=0 \\ m\neq m1}}^{M-1} \alpha_{m}(i) x_{m}(i) \ , \tag{8}$$

$\alpha_m(i)$ in eqn. (8) and (9) is the weight of the contribution from symbol $x_m(i)$, and it is calculated as:

$$\alpha_m(i) = \sum_{j=0}^{P-1} h_{ch}(j) \sum_{l=-\infty}^{\infty} f_m(l) h_{m1}[(i1-i)M - j - l] , \tag{9}$$

where P is the length of channel impulse response $h_{ch}(n)$. The normalized ISI and ICI power at subchannel $m1$, σ_{m1}^2, can be calculated as:

$$\sigma_{m1}^2 = \sum_{\substack{i=-\infty \\ i\neq i1}}^{\infty} \left|\alpha_{m1}(i)\right|^2 + \sum_{i=-\infty}^{\infty} \sum_{\substack{m=0 \\ m\neq m1}}^{M-1} \left|\alpha_{m}(i)\right|^2 , \tag{10}$$

where operator $|\cdot|$ means absolute value.

We take the averaged normalized interference power over M subchannels as our objective function, which is defined as:

$$P_{AV} = \frac{1}{M}\left(\sum_{m1=0}^{M-1} \sigma_{m1}^2\right). \tag{11}$$

3.2 Numerical Simulations for a Fading Channel

System simulation is done for two sample fading channels $h_{ch}(n) = \delta(n) + 0.5e^{j\pi/6}\delta(n-1)$ and $h_{ch}(n) = \delta(n) + 0.5\delta(n-1) + 0.3\delta(n-2)$.

Figure 2 shows the simulation results of P_{AV}, over the first channel, for DFT-based OFDM systems with and without prefix, DWMT and complex-valued M-band filter bank which is designed according to the method described. The prefix inclusive DFT-based OFDM system has better performance over prefix non-inclusive system and DWMT, with cost of system efficiency decreased by a factor of $M/(M+k)$, where k is the length of cyclic prefix and no less than the length of channel. The length of filters, N, for DFT-based filter bank, DWMT and M-band complex-valued wavelet transform are M, $2M$ and $2M$, respectively. Figure 3 shows the results over the second channel for same circumstances as in Figure 1. In both experiments, the complex-valued M-band filter bank demonstrates superior performance in interference reduction than DFT-based OFDM and DWMT.

It is noted that when increasing the filter length, the complex-valued M-band filter bank has better performance in case of averaged power of interference. Figures 4 and 5 show the change of average power of interference with the increase of filter length N over the two sample channels.

4. CONCLUSIONS

In this paper we proposed unitary filter banks for OFDM systems to suppress the effects of interference introduced by fading channels. The unitary filter banks have much flexibility which allows the room of adaptability to different applications. Simulation results show that the proposed filter bank can significantly reduce the averaged power of interference comparable to DFT-based OFDM and DWMT. It is also shown that better performance can be achieved by using longer filters in the designed unitary filter banks.

REFERENCES

[1] S.D. Sandberg and M.A. Tzannes, "Overlapped discrete multitone modulation for high speed copper wire communication," IEEE Journal on Selected Areas in Communications, vol. 13, no.9, pp. 1571-1585, Dec 1995.

[2] H. S. Malvar, "Extended lapped transforms: properties, applications, and fast algorithms," IEEE Trans. Signal Processing, vol.40, no.11, pp. 2703-2714, Nov. 1993.

[3] P.P. Vaidyanathan, "Filter banks in digital communications," IEEE Circuits and Systems Magazine, vol.1, no. 2, pp. 4-25, 2000.

[4] P.P. Vaidyanathan, Multirate Systems and Filter Banks. Englewood Cliffs, NJ: Prentice-Hall, 1992.

[5] H. Zou and A.H. Tewfik, "Discrete orthogonal M-band wavelets decompositions," Proc. Of ICASSP'92, vol. 4, pp 605 -608, May 1992.

[6] P. Steffen, P. Heller, R. Gopinath, and C.S. Burrus, "Theory of regular m-band wavelet bases," IEEE Trans. Signal Processing, vol. 41, no.12, pp. 3497 - 3511 Dec 1993.

[7] X.-P. Zhang, M. Desai and Y.-N. Peng, "Orthogonal complex filter banks and wavelets: some properties and design," IEEE Trans. Signal Processing, vol.47, no. 4, pp. 1039 -1048, Apr. 1999.

[8] Y. Wang and X.-P. Zhang, "Error performance analysis of general OFDM systems with MPSK coding over multipath channels", submitted to ISSPA 2003.

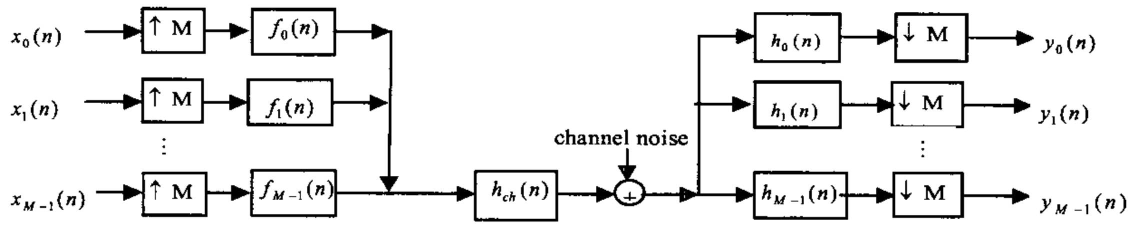

Figure 1. Multirate filter bank based communication system

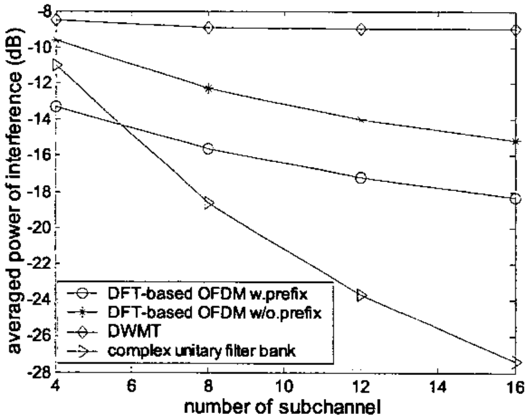

Figure 2. Average power of interference for DFT-based filter bank, DWMT and the new OFDM system based on complex-valued unitary M-band filter bank ($h_{ch}(n)=\delta(n)+0.5e^{j\pi/6}\delta(n-1)$).

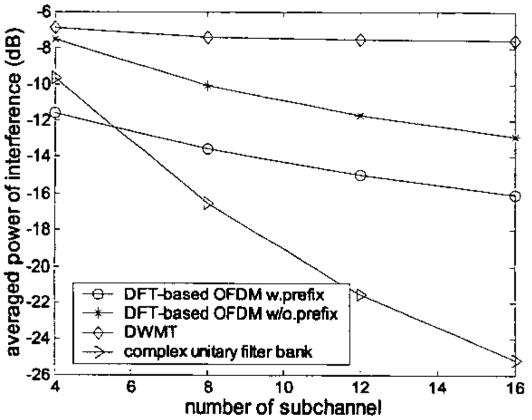

Figure 3. Average power of interference for DFT-based filter bank, DWMT and the new OFDM system based on complex-valued unitary M-band filter bank ($h_{ch}(n)=\delta(n)+0.5\delta(n-1)+0.3\delta(n-2)$).

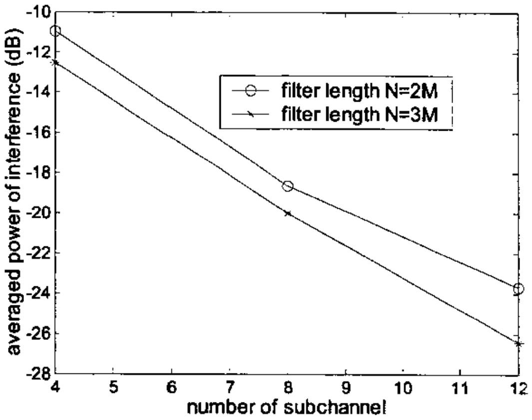

Figure 4. Average power of interference for new OFDM system based on complex-valued unitary M-band filter bank with different length of filter ($h_{ch}(n)=\delta(n)+0.5e^{j\pi/6}\delta(n-1)$).

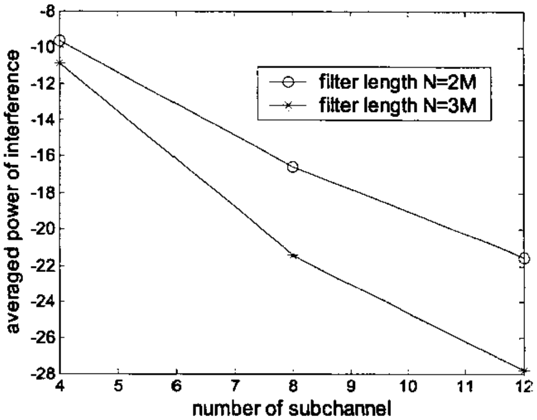

Figure 5. Average power of interference for new OFDM system based on complex-valued unitary M-band filter bank with different length of filter $h_{ch}(n)=\delta(n)+0.5\delta(n-1)+0.3\delta(n-2)$).