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A study on the optimum wavelet filters and spreading sequences for DWT MC-CDMA

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DWT MC-CDMA 시스템을 위한 최적의 웨이브렛 필터 및 확산 순열에 관한 연구

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ABSTRACT

Multi-Carrier Spread Spectrum communications has shown the ability of transform domain excision using the wavelet transformation to improve system performance when transmitting signals in the presence of additive white Gaussian noise and interference. In such work, the transforms were implemented using FIR filters and IIR filter. Some well-known classes of sequences, such as Pseudo noise, Walsh, Gold sequences are evaluated with respect to the basic criteria. The main objective is to implement the wavelet transform using IIR filters. This filters are well known to have sharper transition regions leading to better performance. Numerical simulation of multi-carrier spread spectrum communication systems have shown that IIR filters are better in removing the sinusoidal jammer and subsequently yield better BER performance.

1. INTRODUCTION

Spread Spectrum(:SS) communication techniques have become attractive to wireless communications. Some of the advantages of SS wave forms include their limited immunity to narrow-band interference, transparency to unintended receivers such as intercept receiver, tolerance to multipath effects, and capability for code division multiple access. And the recently proposed multi-carrier CDMA (:MC-CDMA) has a superior survivability in multi-user and inter-chip interferences. In such a system, transmitter data can be easily achieved by using the fast Fourier transform(:FFT). Since each sub-channel involves significant spectral overlaps among neighboring sub-channels, system performance degradation can occur. Since the system performance of a multi-carrier method can be adversely affected by the behavior of sub-channelization, in MC-CDMA channel coding using discrete wavelet transform is utilized in place of FFT.

Some properties of wavelet transforms may make the wavelet transform domain better suited to the suppression of some types of interference than the frequency domain. Recently, it has been shown that discrete wavelet transform multi-carrier CDMA(:DWT MC-CDMA) using FIR filters may yield better performance for jammers. IIR filters are well known to have sharper transition regions for a given order and thus it is expected that they will provide a better energy concentration in the transform domain leading to more effective interference suppression[6]. This paper considers the removing interference in the wavelet transform domain using IIR filters, and performance of optimum spreading code within basing on bit error in gaussian noise channel.

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2. DWT-MC CDMA SYSTEM

The multi-carrier spread spectrum under consideration is shown in Figure 1. The block labeled analysis bank and synthesis bank correspond to the two halves of a perfect reconstruction(PR) quadrature mirror filter bank(QMF). A typical filter bank structure is shown in Figure 2. Each stage of the tree is characterized by a set of filters followed by a downsampling operation. The filters $H_0(z)$ and $H_1(z)$ correspond to low and high pass FIR filters respectively. The filters $G_0(z)$ and $G_1(z)$ interpolate the upsampled signal and are designed to cancel any aliasing effect caused by downsampler. In Figure 2, the structure is a full binary tree which will decompose the input signal $x(n)$ in to four sub-bands.

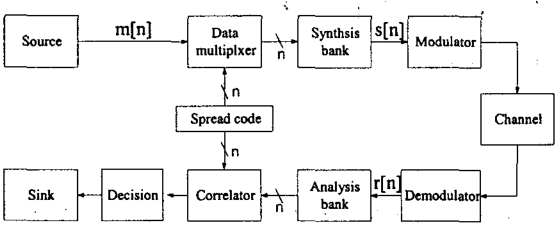

Figure. 1. DWT-MC Spread spectrum system.

At the transmitter, spreading codes are generated using the synthesis filter bank which will perform a linear transformation on a vector containing the message signal. Subsequent message bits are hopped to different position in the input vector, each producing a different spreading code with the polarity being determined by the data bit.

The receiver performs the dual operation to extract the message bit. The corrupted waveform is processed by the analysis filter bank.

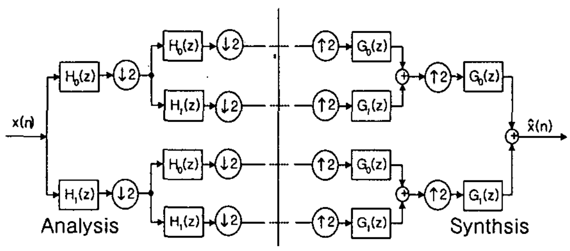

Figure 2. Full binary four-band tree structure

If the analysis and synthesis stage process the PR property, then all of the energy associated with the message will be isolated to a single filter output. spreading of receiver code can then reference this filter output and extract the message signal. The message signal is then passed to a threshold device to make a decision as to its content[4][5].

3. SPREADING WAVEFORM DESIGN

3.1 Orthogonality and Perfect Reconstruction

The orthogonality of the spreading codes and the PR requirement are closely related and are more easily analyzed by the simplest sub-band filter bank shown in Figure 3[4][5][7].

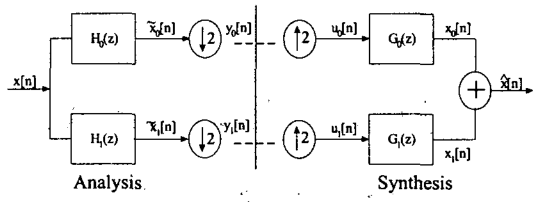

Figure 3. Two-channel sub-band filter bank

The goal of the filter bank described above is $\hat{x}(n) = x(n-n')$ where n' is a positive integer. it can be shown that this possible if the four filters meet certain perfect reconstruction conditions. Specifically, let $h(n)$ be the impulse response of $H_0(z)$.

The conditions for perfect reconstruction are

$$H_1(z) = z^{-(N-1)} H_0(-z^{-1})$$

$$G_0(z) = -H_1(-z), \quad G_1(z) = H_0(-z)$$

$$\sum_{k=0}^{N-1} h_k h_{k+2n} = \delta_n \quad \forall\ n \geq 0$$

where N is the filter order of $H_0(z)$ and δ_n is the unit impulse function. The first condition ensure $H_0(z)$ and $H_1(z)$ are quadrature mirror filters. The next two conditions are needed to eliminate aliasing effects during the reconstruction. The final restriction places $N/2$ conditions on the $H_0(z)$ filter coefficients and ensures perfect reconstruction.

The above conditions also guarantee orthogonal. The cross correlation between two codes is[4][5]

$$R_{g_0 g_1} = \sum_{n=0}^{N-1} g_0(n) g_1(n)$$

$$= \sum_{n=0}^{N-1} (-1)^n h(n) h(N-1-n) = 0$$

These filters are generally implemented as FIR filters which require a high order for a sharp transition band but are computationally stable.

3.2 Design of Butterworth IIR filters

IIR filters give superior performance with better transition region. However, they can be computationally unstable unless proper care is taken. In particular, poles which are inside and close to the unit circle can be forced outside by coefficient quantization effects. It has been shown that IIR filters can be used to implement wavelet transform. In this paper we consider Butterworth filters of order N(odd) with $H_0(z)$ and $H_1(z)$ given by[7]

$$H_0(z)=\frac{\sum_{k=0}^{N}\binom{N}{k}z^{-k}}{\sqrt{2}\sum_{l=0}^{(N-1)/2}\binom{N}{2l}z^{-2l}}$$

$$H_1(z)=z^{-1}H_0(-z^{-1})$$

$$G_0(z)=H_0(z^{-1})$$

$$G_1(z)=H_1(z^{-1})$$

Case of order N=7

$$H_0(z)=\frac{1+7z^{-1}+21z^{-2}+35z^{-3}+35z^{-4}+21z^{-5}+7z^{-6}+z^{-7}}{\sqrt{2}(1+21z^{-2}+35z^{-4}+7z^{-6})}$$

Since the pole of $H_0(z)$ and $H_1(z)$ are both inside and outside the unit circle, each filter must be implemented as a product of a stable left-side and a stable right-side filter. The actual filters are[6]

$$H_0(z)=H_{0r}(z)H_{0l}(z)$$

$$H_1(z)=H_{1r}(z)H_{1l}(z)$$

where

$$H_{0l}(z)=\frac{(1+z^{-1})^4}{(1+4.38128^2z^{-2})(1+1.25396^2z^{-2})}$$

$$H_{0r}(z)=\frac{(1+z^{-1})^3}{\sqrt{2}(1+0.48157^2z^{-2})}$$

$$H_{1l}(z)=\frac{(1-z)^3}{\sqrt{2}(1+0.48157^2z^2)}$$

$$H_{1r}(z)=\frac{z^{-1}(1-z)^4}{(1+4.38128^2z^2)(1+1.25396^2z^2)}$$

Figure 4 shows the analysis section of a two channel PR QMF bank using noncausal IIR filters[6]. The synthesis filter $G_0(z)$ and $G_1(z)$ are time-reversed version of $H_0(z)$ and $H_1(z)$ and the corresponding synthesis section to the analysis section of Figure 3 can be realized by exploiting this relationship. Practically, this section is given only impulse response by transfer function. Then the results presented the H_{0l}, H_{1l}, H_{0r}, H_{1r} filters as given above were approximated by FIR filters by truncating the impulse response. Therefore the method of implementation is same thing of FIR filters.

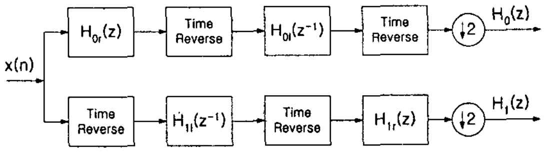

Figure 4. Analysis section

4. SIMULATION AND RESULTS

Monte Carlo simulations was implemented in order to compute of removing jammer efficiency, and performance of optimum spreading code within basing on bit error in gaussian noise channel. The seventh order Butterworth filter, as approximated by a truncated 16 length of impulse response, was used. Discrete wavelet transform followed Figure 2. The received signal consists of 10 chip PN sequence and summed with a jammer and white Gaussian noise.

In Figure 5 the magnitude response of the low pass filter $H_0(z)$ is shown. The tested IIR filter shows better performance than the Daubechies FIR filters. Specially, 40-tap FIR filter response is similar 16-tap IIR filter.

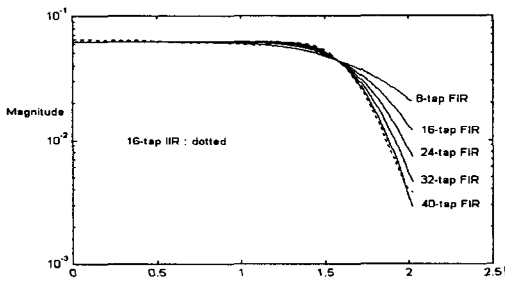

Figure 5. Magnitude response of the tested filters

Figure 6 and 7 show partial removal of a stationary sinusoidal jammer with amplitude of 3 and 7. The figures show that the "best" performance is provided by the IIR filter in the same filter length and similar magnitude response. Obviously the highest order FIR filter tested achieves the performance of the 16-tap IIR filter.

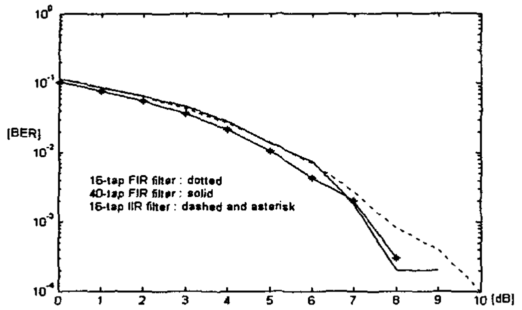

Figure 6. Jammer $i(n) = 3\sin(\omega_0 n)$ results

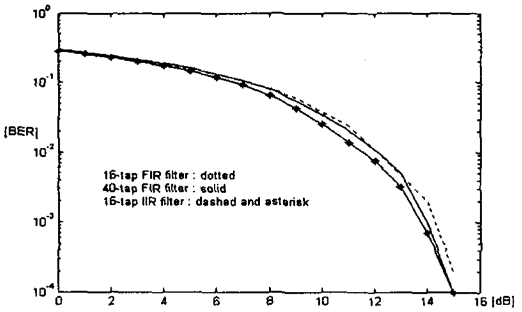

Figure 7. Jammer $i(n) = 7\sin(\omega_0 n)$ results

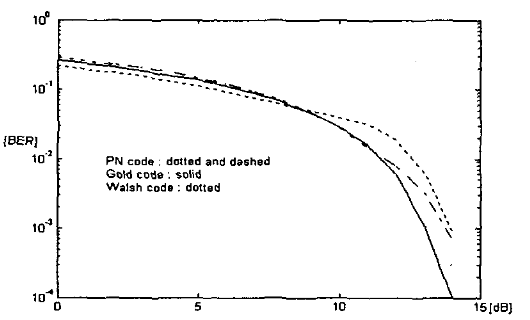

Figure 8. Optimum code test results

Figure 8 shows performance of optimum spreading code within basing on bit error in presented jammer and gaussian noise channel. Tested spreading codes are PN of length 31, Gold of length 31 and Walsh of length 32. The Walsh code is optimum in a less signal-to-noise environment and the Gold code is optimum in over 8 dB SNR environment. Although not shown other jammer amplitude, these results followed similar plot format.

5. CONCLUSION

The performance of the IIR based wavelet transform for a multi-carrier spread spectrum system was studied. The resulting signal was transmitted over an added white Gaussian noise channel with sinusoidal jammers. The IIR filter banks were compared to FIR filters whose coefficient where derived from Daubechies wavelets [8]. Results show that the IIR filter banks performed superior to those of Daubechies while being more efficient in terms of BER. The Walsh code is optimum in a less SNR environment and the Gold code is optimum in over 8 dB SNR environment. Implementation of Figure 2 does not take advantage of the fact that half of the computed values are discarded through downsampling. A polyphase method avoids unused computations. The polyphase approach of wavelet transform can decrease computation cost.

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