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Research of OFDM System ICI Suppression Method Based on Orthogonal Wavelet

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Abstract: In order to improve the performance of Orthogonal Frequency division Multiplexing (OFDM) system, eliminate adverse effects on the Inter-Carrier Interference (ICI) caused by the OFDM system, Using orthogonal wavelet instead of discrete Fourier transform, optimize the design for OFDM systems, on the premise of without protection interval to reduce the system interference, using MATLAB to simulate the OFDM system, results show that the optimization of the OFDM can reduce the power of the ICI and improve the comprehensive anti-jamming of the OFDM system.

Key words: Orthogonal frequency division multiplexing, orthogonal wavelets, discrete fourier transform, anti-interference ability

INTRODUCTION

OFDM system through the Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) to achieve modulation and demodulation, which is a kind of multicarrier parallel transmission scheme, divide the channel into several sub channels and put the high-speed serial data stream convert into a number of sub data stream whose rate is relatively slow and the data is parallel, also modulation the signal for each sub channels, at the same time make each signal to be orthogonally, so, that spectrum overlap each other, thus improving the efficiency of the spectrum and reduce the mutual interference between channels. However, there are also some disadvantages in OFDM system, when a frequency comes to offset, it will appear overlapping of the sub channels spectrum and destroy the subcarrier orthogonally, causing the ICI (Bao and Zhang, 2007). When the phases of signals on the sub channels are the same, after the signal superposition, the instantaneous power will be greater than the average power, which changes the frequency and the signal waveform distortion and thus destroy the orthogonally of the sub channels. Conventional OFDM copying the parts signals in the end to the front by inserting protection interval to form a cyclic Prefix (CP), making the protection interval greater than multipath time delay, in order to make sure that the discrete Fourier transform signal phase do not change when calculate. Make symbol of the N synchronous transmission from much impact, thereby overcoming the problem of the ISI. But once the multipath is greater than the protection interval, the signal phase may change when using the DFT calculations (Gao *et al*., 2006), then the signal received by the receiver can no longer guaranteed only component by the simple and continuous sinusoidal, may have damaged the orthogonal of the sub carrier and reduce the transmission of the system. In this study, put forward to a method based on the orthogonal wavelet OFDM, the main idea is to select the appropriate orthogonal instead of the DFT, in order to reduce ICI without protection interval, the wavelet theory is a time-frequency method, so that analysis and analysis of signal in time domain and frequency domain.

OFDM MODULATION AND DEMODULATION PRINCIPLE

OFDM is a kind of parallel modulation technique that using the extension of the transmitted symbols cycle to resist multipath interference. First thing to do is channel code for the input information sequence, according to the selection of modulation method to complete corresponding modulation and then to obtain a modulation sequence $\{d_n\}$. And using IDFT for $\{d_n\}$, converting the data in frequency domain to the time domain and in order to obtain the time domain sample sequence of the modulated signal, after adding the guard interval, then to the time domain sequence for digital conversion, finally get the time domain waveform of the modulated OFDM signal. In the receiver, convert the frequency of the signal and to protect the interval operation to obtain the sample sequence of the modulated OFDM signal, the sequence for DFT and then get the original modulation sequence $\{d'_n\}$. High speed serial data stream is divided into several parallel data with low rate (Wang and Yan, 2013). The available spectrum is cut by subcarriers with relatively narrow frequency band and the amplitude-frequency response of all the subcarriers

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keeps orthogonal and overlapping. Then, the parallel data modulates corresponding orthogonal subcarriers to get the modulated signal. Due to the orthogonality among subcarriers, OFDM can avoid ICI. However, multipath fading and time delay cause frequency deviation of multi-carrier system, which destroys the orthogonality among subcarriers, thus, leading to ICI. The channel multipath effect aggravates ICI and also causes ISI . By inserting protecion interval, conventional OFDM copies the signal at the end part to the front part, to format CP (Cyclic Prefix). When protection interval is greater than the multipath time delay, signal phase remains the same, during DFT calculation, to make that the synchronous transmission symbol is not affected too much, thus ICI can be overcome. But, once protection interval is less than the multipath time delay, signal phase jumps during DFT calculation, so the signal at the receiving end, is not composed of simple and continuous sinusoidal signal. Thus, the orthogonality among subcarriers is damaged and the system transmission efficiency is reduced. Synthetic transmission signal D (t) is expressed as followings:

$$D(t)=\sum_{i=0}^{N-1}(a_i+jb_i)(\cos\omega_i t+j\sin\omega_i t)=\sum_{i=0}^{N-1}di\bullet\exp(j\omega_i t) \tag{1}$$

As the sampling rate f_s for sampling D (t), the serial symbol interval $\Delta t = 1/f_s$, a total of N samples values in a cycle, make the sampling interval $t = n\Delta t$, then a signal sample sequence D (n) can denote as the IDFT of the sequence $\{d_i\}$ which I = 0~N-1:

$$D(n)=\sum_{i=0}^{N-1}d_i\cdot\exp(2\pi in/N)=\text{IDFT}\{d_i\},0\le n\le N-1 \tag{2}$$

D (n) is the result of symbol sequence $\{d_i\}$ which the point N discrete Fourier inverse transform, thus indicating the IDFT operation can be achieved the baseband modulation signal of the OFDM system. DFT to complete the baseband signal demodulation.

D (n) has N samples in total, each input of the subcarrier has a sampling point, then, a plurality of continuous signals can be expressed as followings:

$$D(kN+n)=\sum_{i=0}^{N-1}d_i(k)\bullet e^{j2\pi in/N} \tag{3}$$

$n = 0,1\ldots N-1;-\infty<k<\infty k\in Z$, so d_i (k) equals to:

$$d_i\left[\frac{kN+n-m}{N}\right]=\begin{cases}d_i(k) & m=n\\ 0 & \text{else}\end{cases} \tag{4}$$

$$d_i(k)e^{j2\pi in/N}=\sum_{m=0}^{N-1}d_i\left(\frac{kN+n-m}{N}\right)e^{j2\pi in/N}=d_i\left(\frac{kN+n}{N}\right)*e^{j2\pi in/N} \tag{5}$$

The core algorithm of OFDM is DFT, based on the theory of filter bank, the IDFT of the sender D (t) were classified as the input of the each subcarrier d_I (kN+n), after the growth factor of N sampled achieved:

$$d_i(\frac{kN+n}{N})$$

then with the filter impulse response convolution of $e^{j2\pi in/N}$. The DFT of the receiver D′ (t) can be consider as the received signals convolution with the filter which the impulse response is $e^{j2\pi in/N}$, then a reduction of sample N. The filter which shown as the dashed box in Fig. 1

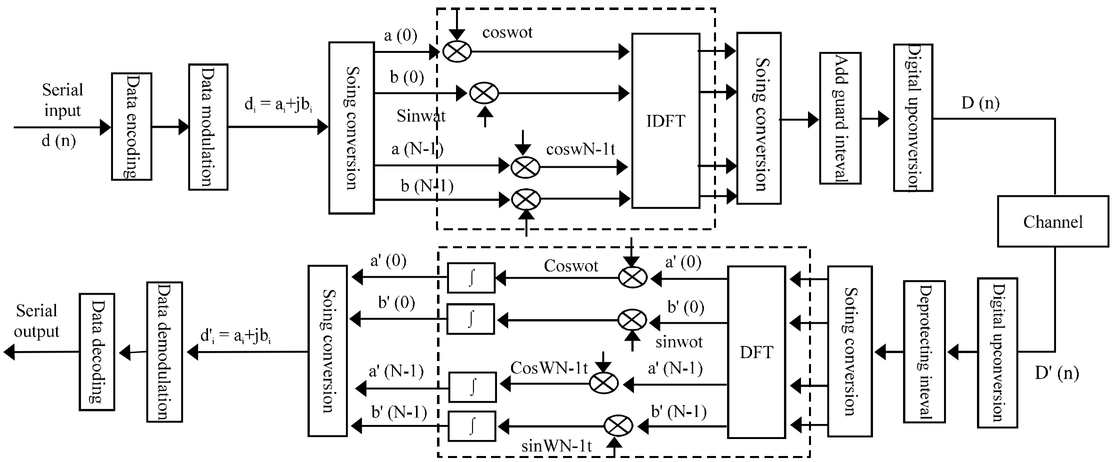

Fig. 1: OFDM modulation and demodulation schematics

composed of discrete cosine function can be expressed as followings:

$$h_i(n)=\sqrt{\frac{2}{N}}\cos\left[\frac{\pi(2n+1)(2i+1)}{4N}\right] \tag{6}$$

$n = 0,1,\ldots,n\text{-}1;\ i = 0,1,\ldots,n\text{-}1$.

OFDM OF THE ORTHOGONAL WAVELET OPTIMAZITION

Analysis of the optimization OFDM: Conventional OFDM system uses complex exponential subcarriers which consists of orthogonal cosine functions, the core algorithm is the DFT, according to the theory of wavelet transform, select the appropriate orthogonal wavelet instead of the DFT, on the premise of without protection interval, reducing the ICI and ISI, because the wavelet theory is a time-frequency method, resulting that analysis signal in both of them.

Multi-resolution analysis of the wavelet,filtering function usually acts as by scale function φ (t) and wavelet function ι (t), using orthogonal wavelet multicarrier OFDM system, calculated by the Quadrature Mirror Filter (QMF), obtained for each sub channel equivalent filter, the perfect reconstruction condition can be achieved through the selection of appropriate filter. Mallet algorithm, the scaling function is related to the low-pass digital filter and the wavelet function associated with a high-pass digital filter, mallet algorithm uses a recursive calculations, using two filters filtering the original discrete signals and then do down-sampling which the coefficient is 2, were obtained crude resolution discrete approximation signal and discrete detail signal, then down sampling for the latter to obtain more coarse resolution discrete approximation signals and discrete detail signals, which is the discrete wavelet transform system. The originator of the multicarrier OFDM, parallel transmission of each subcarrier signal superimposed equivalent to the wavelet reconstruction algorithm; receiving for each sub-carrier signal process is equivalent to the wavelet decomposition algorithm (Wang *et al*., 2008). Signal reconstruction network structure as shown in Fig. 2.

According to the principle of multi-rate transform and filter cascade operation (Zhang *et al*., 2006), using the N pathway filter group to replace the conventional OFDM, which h_0 (n), h_1 (n)… h_{N-2} (n) corresponds to the high-pass filter of the wavelet reconstruction and h_{N-1} (n) corresponds to the low-pass filter:

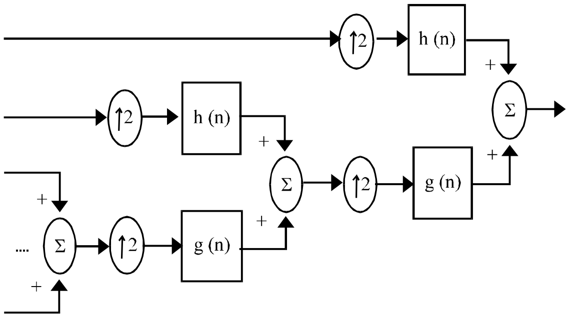

Fig. 2: Network structure of the signal reconstruction

$$h_i(n)=\begin{cases} h(n)\big|_{\uparrow 2^i} * \prod_{k=0}^{i-1} g(n)\big|_{\uparrow 2^k} & i=0,1,\cdots N\text{-}2 \\ \prod_{i=0}^{N-2} g(n)\big|_{\uparrow 2^k} & i=N-1 \end{cases} \tag{7}$$

$$n_i=\begin{cases} 2^{i+1} & i=0,1,\cdots N\text{-}2 \\ 2^{N+1} & i=N-1 \end{cases} \tag{8}$$

$$l_i=\begin{cases} \left(2^{i+1}-1\right)(1-1) & i=0,1,\cdots N-2 \\ l_{N-2} & i=N-1 \end{cases} \tag{9}$$

The orthogonality of each sub channel is expressed as followings:

$$\left\{h_i(n) * h_k^*(-n)\right\}\big|_{\downarrow n_k}=\sum_{m=0}^{l_i} h_i(m)\bullet h_k^*(m-n_k n)=\delta[i-k]\bullet\delta[n] \tag{10}$$

The N-channel filter of the OFDM system transmission signal D (n) as followings:

$$D(n)=\sum_{j=0}^{N-1}\left[d_j(n)\big|_{\uparrow n_j} * h_j(n)\right] \tag{11}$$

Interference analysis: In order to facilitate analysis and calculation, the channel is equivalent to one path with the reference model, two-path channel transmission characteristics as followings:

$$H(w)=1+e^{-jw\tau} \tag{12}$$

IDFT transform for channel transmission characteristics and quantization sample, obtained under the discrete time, channel impulse response as followings:

$$h_c(n)=a\delta(n)+b\delta(n-\tau) \tag{13}$$

Then, the signal through the transmission can be expressed as followings:

$$
\begin{aligned}
D'(n) &= D(n) * h_c(n) \\
&= \sum_{j=0}^{N-1}\left[d_j(n)\Big|_{\uparrow n_j} * h_j(n)\right] * \left[a\delta(n) + b\delta(n-\tau)\right] \\
&= a\sum_{j=0}^{N-1}\left[d_j(n)\Big|_{\uparrow n_j} * h_j(n)\right] + b\sum_{j=0}^{N-1}\left[d_j(n)\Big|_{\uparrow n_j} * h_j(n-\tau)\right]
\end{aligned} \tag{14}
$$

But:

$$\left\{h_j(n) * h_i^*(-n)\right\}\Big|_{\downarrow n_i} = \sum_{m=0}^{N-1} h_j(m)h_i^*(m-n_i n) = \delta(j-i)\delta(n) \tag{15}$$

$$\left\{h_j(n-\tau) * h_i^*(-n)\right\}\Big|_{\downarrow n_i} = \sum_{m=-\infty}^{\infty} h_j(m-\tau)h_i^{\times}(m-n_i n) \tag{16}$$

So, output of the receiver d′ (n) can be denoted as followings:

$$
\begin{aligned}
d_i'(n) &= \left[D'(n) * h_i^*(-n)\right]\Big|_{\downarrow n_i} \\
&= a\sum_{j=0}^{N-1} d_j(n)\Big|\uparrow(n_j/n_i) * \left[h_j(n) * h_i^*(-n)\right]\Big|_{\downarrow n_i} + b\sum_{j=0}^{N-1} d_j(n)\Big|\uparrow(n_j/n_i) * \left[h_j(n-\tau) * h_i^*(-n)\right]\Big|_{\downarrow n_i} \\
&= a\sum_{j=0}^{N-1} d_j\left(\frac{n_j}{n_i}\bullet n\right) * \left[\delta(j-i)\delta(n)\right] + b\sum_{j=0}^{N-1} d_j\left(\frac{n_j}{n_i}\bullet n\right) * \left[\sum_{m=-\infty}^{\infty} h_j(m-\tau)h_i^*(m-n_i n)\right] \\
&= a\sum_{j=0}^{N-1} d_j\left(\frac{n_j}{n_i}\bullet n\right) * \delta(j-i) + b\sum_{j=0}^{N-1}\sum_{m=-\infty}^{\infty} h_j(m-\tau)\sum_{k=-\infty}^{\infty} d_j\left(\frac{n_j}{n_i}\bullet k\right) h_i^*\left[m - n_i\left(n \bullet \frac{n_j}{n_i}\bullet k\right)\right] \\
&= ad_i(n) + b\sum_{j=0}^{N-1}\sum_{k=-\infty}^{\infty} h_j(m-\tau)h_i^*(m - nn_i + n_j k)
\end{aligned} \tag{17}
$$

i = j, k = n, the useful signal from the receiver as followings:

$$
\begin{aligned}
d_i'(n) &= ad_i(n) + bd_i(n)\sum_{m=-\infty}^{\infty} h_j(m-\tau)h_i^*(m) \\
&= \left[a + b\sum_{m=-\infty}^{\infty} h_j(m-\tau)h_i^*(m)\right] d_i(n)
\end{aligned} \tag{18}
$$

i = j, k≠n get the inter-symbol interference (ISI) as followings:

$$d_i'(n) = ad_i(n) + b\sum_{\substack{k=-\infty \\ k\neq n}}^{\infty} d_i(k)\sum_{m=-\infty}^{\infty} h_j(m-\tau)h_i^*(m - nn_i + n_i k) \tag{19}$$

i≠j, get the inter-channel interference (ICI) as followings:

$$d_i'(n) = ad_i(n) + b\sum_{\substack{j=0 \\ j\neq i}}^{N-1}\sum_{k=-\infty}^{\infty} h_j(m-\tau)h_i^*(m - n_i n + n_j k) \tag{20}$$

According to 2 and 3 get the power of ISI and ICI are as followings:

$$P_{ISIi} = \sum_{\substack{k=-\infty \\ k\neq 0}}^{\infty}\left|\sum_{m=-\infty}^{\infty} h_i(m-\tau)h_i^*(m - n_i k)\right|^2 \tag{21}$$

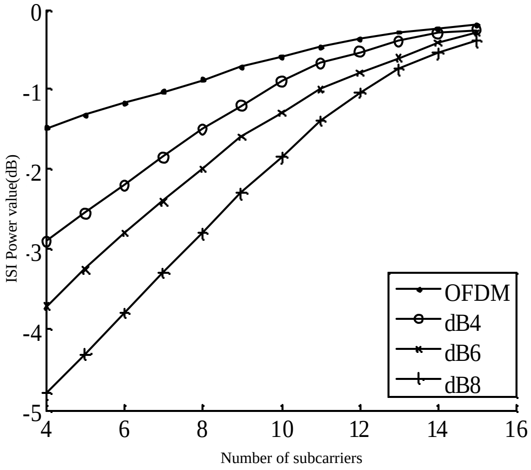

Fig. 3: ISI compare between traditional OFDM and OFDM based on wavelet

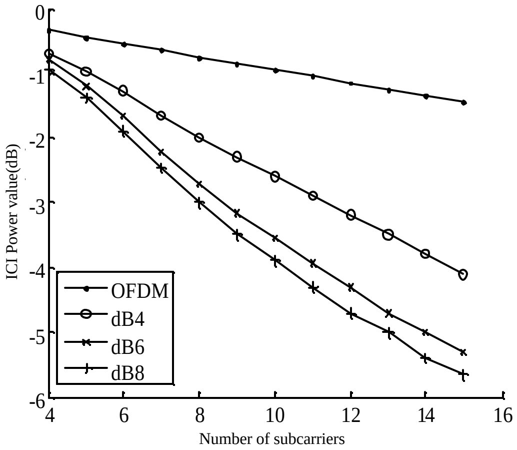

Fig. 4: ICI compare between traditional OFDM and OFDM based on wavelet

$$P_{ICIi} = \sum_{\substack{j=0 \\ j\neq i}}^{N-1}\sum_{k=-\infty}^{\infty}\left|\sum_{m=-\infty}^{\infty} h_j(m-\tau)h_i^*(m - n_j k)\right|^2 \tag{22}$$

SIMULATION ANALYSIS

In order to verify the feasibility of improved algorithm, this study using MATLAB as a simulation platform to compare the optimize OFDM with the conventional OFDM. Using the 2, 3, 4 order of the Daubechies wavelet, according to 21, 22 for simulation and get the ISI and ICI on each sub-carrier power value. The simulation results as shown in Fig. 3 and 4.

According to the simulation results can be seen the anti interference of OFDM system based on the wavelet is superior than the conventional OFDM and with the increase of the wavelet order, the number of ICI and ISI decreased gradually carrier power value. The simulation results as shown in Fig. 3 and 4.

CONCLUSION

In this study, to improve the existing OFDM, use orthogonal wavelet instead of DFT, so as to achieve the design of OFDM system and simulation for the two OFDM systems in the channel, the simulation results show that the OFDM system based on orthogonal wavelet reduced the interference power and improved the system anti-jamming ability.

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