International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)
Volume-1 Number-1 Issue-1 September 2011

An Analytical Approach for Efficient OFDM Modulator and Demodulator Communication Systems Based on Discrete Hartley Transform

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Abstract

The main drawback of OFDM is its high peak to average power ratio (PAPR). High PAPR of OFDM makes it unusable in non-linear systems. So the clipping signals scheme is one useful and simple method to reduce the PAR. In the widely used OFDM (Orthogonal Frequency Division Multiplexing) systems, the FFT and IFFT pair is used to modulate and demodulate the data constellation on the subcarriers. This paper presents a high level implementation of a high performance FFT for OFDM Modulator and Demodulator. In this paper we analyzes several aspects of discrete Hartley transform (DHT) as an alternative to replace the conventional complex valued and mature discrete Fourier transform (DFT) as OFDM .The random binary data was generated and transmitted via the dispersive channel with using additive white Gaussian noise (AWGN) channel model. We also analyze several aspects on the performance of the system was which valuated by calculating the number of bit errors for several value of signal to noise ratio (SNR).As compared to the conventional method we also compare so that we can improve the power of the system.

Keywords

OFDM, PAPR, DHT, DFT

1. Introduction

Orthogonal frequency-division multiplexing (OFDM) is a multicarrier transmission technique which is widely adopted in different communication applications. OFDM prevents inter symbol interference by inserting a guard interval, and mitigates the frequency selectivity of a multipath channel by using a simple equalizer. This simplifies the design of the receiver and leads to inexpensive hardware implementations.

OFDM technique has attracted much interest for its advantages, such as the high spectrum efficiency, interference rejection capability, security and so on [1-4]. OFDM modulation is done by IFFT and OFDM demodulation is done by FFT. The FFT algorithm eliminates the redundant calculation which is needed in computing Discrete Fourier Transform (DFT) and is thus very suitable for efficient hardware implementation [5]. Most of OFDM transceivers employ IFFT and FFT to perform modulation and demodulation in transmitter and receiver, respectively. For the current DFT-based OFDM transceivers, the modulator needs to compute a long-length inverse discrete Fourier transform (IDFT), and the demodulator needs to compute a long-length DFT, where the transform length is up to 512 or more [6,7,8].

Usually, base-band signal is up-converted to radio frequency before transmission over antenna. In the receiver side, RF signal is down-converted to base-band and processed digitally. Because OFDM signal is a complex signal, up-conversion requires both cosine and sine waveforms.

The conventional method use the FFT computation result for parameter estimation, the accuration is very low for "spectrum leakage" and limited spectrum precision. If higher accuration is required, zero adding or higher sampling rate is needed, therefore the computation complexity is very high and can't cooperate with the demodulation module very well. To solve this problem, the new scheme the using two max bin of FFT computation result for parameter estimation by equations computation without zero adding or higher sampling rate, possessing the advantage of low computation complexity, high accuration and cooperation with the demodulation module.

The increasing growth of wireless communication requires high data-rate capable technologies. Novel techniques such as OFDM and MIMO stand as promising choices for future high data-rate systems [9]. MIMO-OFDM can be implemented to achieve a low error rate and high data rate by flexibly exploiting the diversity gain and the spatial multiplexing gain [10]. Realizing these gains requires the channel state information (CSI) at the receiver, which is often obtained through channel estimation. As we can analyzes several aspects for efficient OFDM. In this paper we discuss several aspects of FFT and OFDM. We also discuss discrete Hartley Transformation and there several aspects.

The remaining of this paper is organized as follows. We discuss OFDM and FFT in Section 2. In Section

3 we discuss about Discrete Hartley Transformation. In section 4 we discuss about Evolution and Recent Scenario. In section 5 we discuss about the proposed scheme. The conclusions and future directions are given in Section 6. Finally references are given.

2. OFDM and FFT

The main reason that the OFDM technique has taken a long time to become a prominence has been practical. It has been difficult to generate such a signal, and even harder to receive and demodulate the signal. The hardware solution, which makes use of multiple modulators and demodulators, was somewhat impractical for use in the civil systems.

The ability to define the signal in the frequency domain, in software on VLSI processors, and to generate the signal using the inverse Fourier transform is the key to its current popularity. The use of the reverse process in the receiver is essential if cheap and reliable receivers are to be readily available. Although the original proposals were made a long time ago [Weinstein and Ebert], it has taken some time for technology to catch up.

At the transmitter, the signal is defined in the frequency domain. It is a sampled digital signal, and it is defined such that the discrete Fourier spectrum exists only at discrete frequencies. Each OFDM carrier corresponds to one element of this discrete Fourier spectrum. The amplitudes and phases of the carriers depend on the data to be transmitted. The data transitions are synchronised at the carriers, and can be processed together, symbol by symbol (Fig. 1).

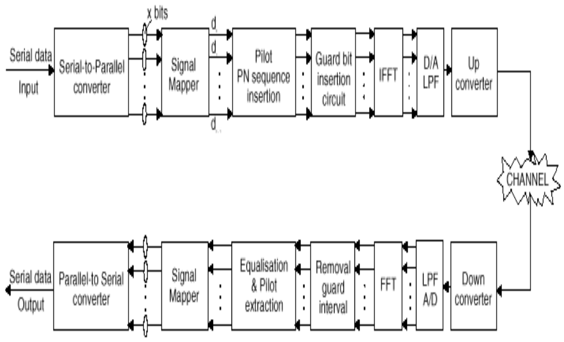

Fig 1. Block diagram of an OFDM system using FFT, pilot PN sequence and a guard bit insertion [Zou and Wu]

The definition of the (N-point) discrete Fourier transform (DFT) is:

$$X_p[k] = \sum_{n=0}^{N-1} x_p[n] e^{-j(2\pi/N)kn}$$

and the (N-point) inverse discrete Fourier transform (IDFT):

$$x_p[n] = \frac{1}{N}\sum_{k=0}^{N-1} X_p[k] e^{j(2\pi/N)kn}$$

A natural consequence of this method is that it allows us to generate carriers that are orthogonal. The members of an orthogonal set are linearly independent.

Consider a data sequence (d_0, d_1, d_2, …, d_{N-1}), where each d_n is a complex number $d_n=a_n+jb_n$. (a_n, $b_n=\pm 1$ for QPSK, a_n, $b_n=\pm 1, \pm 3$ for 16QAM, …)

$$D_k = \sum_{n=0}^{N-1} d_n e^{-j(2\pi nk/N)} = \sum_{n=0}^{N-1} d_n e^{-j2\pi f_n t_k}$$

K=0 to n-1

Where f_n=n/(ND T), t_k=kD t and D t is an arbitrarily chosen symbol duration of the serial data sequence d_n. The real part of the vector D has components

$$Y_k = \mathrm{Re}\{D_k\} = \sum_{n=0}^{N-1}\left[\left(a_n \cos(2\pi f_n t_k) + b_n \sin(2\pi f_n t_k)\right)\right]$$

If these components are applied to a low-pass filter at time intervals D t, a signal is obtained that closely approximates the frequency division multiplexed signal

$$y(t) = \sum_{n=0}^{N-1}\left[\left(a_n \cos(2\pi f_n t_k) + b_n \sin(2\pi f_n t_k)\right)\right], \qquad 0 \le t \le N\Delta t$$

The orthogonality of sub channels in OFDM can be maintained and individual sub channels can be completely separated by the FFT at the receiver when there are no intersymbol interference (ISI) and intercarrier interference (ICI) introduced by transmission channel distortion. In practice these conditions cannot be obtained. Since the spectra of an OFDM signal is not strictly band limited (sinc(f) function), linear distortion such as multipath cause each sub channel to spread energy into the adjacent channels and consequently cause ISI. A simple solution is to increase symbol duration or the number of carriers so that distortion becomes insignificant. However, this method may be difficult to implement in terms of carrier stability, Doppler shift, FFT size and latency.

One way to prevent ISI is to create a cyclically extended guard interval (Fig. 7), where each OFDM symbol is preceded by a periodic extension of the signal itself. The total symbol duration is $T_{total}=T_g+T$, where T_g is the guard interval and T is the useful symbol duration.

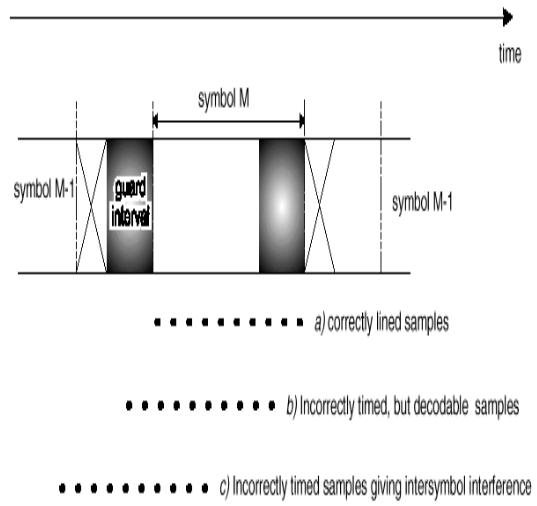

Fig 2. The effect on the timing tolerance of adding a guard interval.

3. Discrete Hartley Transformation

A discrete Hartley transform (DHT) is a Fourier-related transform of discrete, periodic data similar to the discrete Fourier transform (DFT), with analogous applications in signal processing and related fields. Its main distinction from the DFT is that it transforms real inputs to real outputs, with no intrinsic involvement ofcomplex numbers. Just as the DFT is the discrete analogue of the continuous Fourier transform, the DHT is the discrete analogue of the continuous Hartley transform, introduced by R. V. L. Hartley in 1942.

Formally, the discrete Hartley transform is a linear, invertible function H : R^n -> R^n (where R denotes the set of real numbers). The N real numbers x_0, ..., x_{N-1} are transformed into the N real numbers H_0, ..., H_{N-1} according to the formula

$$H_k = \sum_{n=0}^{N-1} x_n \left[\cos\left(\frac{2\pi}{N}nk\right) + \sin\left(\frac{2\pi}{N}nk\right)\right] \qquad k = 0, \ldots, N-1$$

The combination $\cos(z) + \sin(z) = \sqrt{2}\cos(z - \frac{\pi}{4})$ is sometimes denoted $\text{cas}(z)$, and should be contrasted with the $e^{-iz} = \cos(z) - i\sin(z)$ that appears in the DFT definition (where i is the imaginary unit).

As with the DFT, the overall scale factor in front of the transform and the sign of the sine term are a matter of convention. Although these conventions occasionally vary between authors, they do not affect the essential properties of the transform.
The Hartley transform of a function *f*(*t*) is defined by:

$$H(\omega) = \{\mathcal{H}f\}(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t)\,\text{cas}(\omega t)\mathrm{d}t,$$

where ω can in applications be an angular frequency and

$$\text{cas}(t) = \cos(t) + \sin(t) = \sqrt{2}\sin(t + \pi/4) = \sqrt{2}\cos(t - \pi/4)$$

is the cosine-and-sine or *Hartley* kernel. In engineering terms, this transform takes a signal (function) from the time-domain to the Hartley spectral domain.

This transform differs from the classic Fourier transform $F(\omega) = \mathcal{F}\{f(t)\}(\omega)$ in the choice of the kernel. In the Fourier transform, we have the exponential kernel:

$$\exp(-i\omega t) = \cos(\omega t) - i\sin(\omega t),$$

where *i* is the imaginary unit.

The two transforms are closely related, however, and the Fourier transform (assuming it uses the same $1/\sqrt{2\pi}$ normalization convention) can be computed from the Hartley transform via:

$$F(\omega) = \frac{H(\omega) + H(-\omega)}{2} - i\frac{H(\omega) - H(-\omega)}{2}$$

That is, the real and imaginary parts of the Fourier transform are simply given by the even and odd parts of the Hartley transform, respectively.

Conversely, for real-valued functions *f*(*t*), the Hartley transform is given from the Fourier transform's real and imaginary parts:

$$\{\mathcal{H}f\} = \Re\{\mathcal{F}f\} - \Im\{\mathcal{F}f\} = \Re\{\mathcal{F}f \cdot (1+i)\}$$

where $\Re$ and $\Im$ denote the real and imaginary parts of the complex Fourier transform.The Hartley transform is a real linear operator, and is symmetric (and Hermitian). From the symmetric and self-inverse properties, it follows that the transform is aunitary operator .

There is also an analogue of the convolution theorem for the Hartley transform. If two functions *x*(*t*) and *y*(*t*) have Hartley transforms *X*(ω) and *Y*(ω), respectively, then their convolution *z*(*t*) = *x* * *y* has the Hartley transform:

$$Z(\omega) = \{H(x*y)\} = \sqrt{2\pi}\left(X(\omega)\left[Y(\omega) + Y(-\omega)\right] + X(-\omega)\left[Y(\omega) - Y(-\omega)\right]\right)/2$$

Similar to the Fourier transform, the Hartley transform of an even/odd function is even/odd, respectively.

The properties of the *cas* function follow directly from trigonometry, and its definition as a phase-shifted trigonometric function $\mathrm{cas}(t) = \sqrt{2}\sin(t + \pi/4)$. For example, it has an angle-addition identity of:

$$2\mathrm{cas}(a+b) = \mathrm{cas}(a)\mathrm{cas}(b) + \mathrm{cas}(-a)\mathrm{cas}(b) + \mathrm{cas}(a)\mathrm{cas}(-b) - \mathrm{cas}(-a)\mathrm{cas}(-b)$$

Additionally:

$$\mathrm{cas}(a+b) = \cos(a)\mathrm{cas}(b) + \sin(a)\mathrm{cas}(-b) = \cos(b)\mathrm{cas}(a) + \sin(b)\mathrm{cas}(-a)$$

and its derivative is given by:

$$\mathrm{cas}'(a) = \frac{\mathrm{d}}{\mathrm{d}a}\mathrm{cas}(a) = \cos(a) - \sin(a) = \mathrm{cas}(-a)$$

4. Evolution Recent Scenario

In 2009 Peng Xu et al. [11] MAP algorithm for MIMO-OFDM is proposed. This algorithm which uses the characteristic of Expectation maximum (EM) algorithm decrease high complexity. To improve the data transmission efficiency and the performance of channel estimation, joint estimation is carried out over multiple OFDM symbols. Besides, depending on the spatial independence of MIMO channel in angle domain, the dimension-reduced MAP algorithm will be enhanced.

In 2010, K.Harikrishna et al. [12] proposed about a high level implementation of a high performance FFT for OFDM Modulator and Demodulator. The design has been coded in Verilog and targeted into Xilinx Spartan3 FPGAs. Radix-22 Algorithm is proposed and used for the OFDM communication system. This algorithm has the same multiplicative complexity as the radix-4 algorithm, but retains the butterfly structure of radix-2 algorithm.

In 2010, Xiaoqing Wang et al. [13] proposed about an efficient rate adaptive low density parity check (LDPC) coded modulation (RALCM) algorithm is proposed, which maximizes the payload rate for OFDM systems under the constraint of the given transmit power and the target bit error rate (BER). Taking advantage of the two dimensional look up table for the signal to noise ratio (SNR) thresholds, the RALCM algorithm assigns different combinations of the LDPC code rates and quadrature amplitude modulation (QAM) modulations for subcarriers according to the channel frequency response (CFR).

In 2011, Zakaria Sembiring et al. [14] perform an investigation on discrete Hartley transform (DHT) as an alternative to replace the conventional complex valued and mature discrete Fourier transform (DFT) as OFDM modulator and demodulator was carried out in this research. The random binary data was generated and transmitted via the dispersive channel with using additive white Gaussian noise AWGN) channel model. The performance of the system was evaluated by calculating the number of bit errors for several value of signal to noise ratio (SNR).

5. Proposed Scheme

The new DHT-OFDM system for efficient modulator and demodulator is designed in such manner that is perform random generation with Binary Phase Shift Keying (BPSK) then it is applied to the flat fading channel.

After IFFT, the signal is converted form parallel to serial at P/S converter to transmit. The sampled signal of time domain signal x(t) is where x= x0,x1…xLn-1. L is an integer that larger or equal 1 called over-sampling factor. When 1 = L , the samples are achieved by use of Nyquist rate sampling. The "L-time over-sampled" time domain signal samples can be obtained

$$x_k = \frac{1}{N}\sum_{n=0}^{N-1} X_n e^{j2\pi\frac{nk}{LN}} \qquad k = 0,1,\ldots,LN-1$$

Transmitted signal is

$$s(t) = I(t)\cos\omega_c t + Q(t)\sin\omega_c t$$

The implication of the above relation is combined with

$$y(t) = \sum_{n=0}^{N-1} X_n e^{j2\pi\cdot f_n\cdot t}, \quad 0 \le t \le T$$

One major difficulty with OFDM is its large peak-to average power ratio (PAPR) which distorts the signal if the transmitter contains nonlinear components. The PAPR is defined as:

$$PAPR = \frac{\max|y(t)|^2}{P_{av}}, \ 0 \le t \le T$$

where *av P* is the average power of the transmitted symbol and the maximum is sought over the symbol duration. Note that the PAPR in is defined for the average power *av P* measured *after* clipping and filtering. Consider the OFDM signal of sampled at time intervals *GN T t* = Δ , where G is the oversampling factor. The discrete-time OFDM signal sampled at time instant *t=del nt* is then expressed

$$y_n = y(n\Delta t) = \sum_{l=0}^{L-1} X_n e^{j2\pi \cdot n \cdot l/GN}$$

6. Conclusion and Future Directions

We analyze several aspects based on OFDM with FFT. We also discuss the basic elementary components of DHT .This paper presents a high level implementation of a high performance FFT for OFDM Modulator and Demodulator. In this paper we analyzes several aspects of discrete Hartley transform (DHT) as an alternative to replace the conventional complex valued and mature discrete Fourier transform (DFT) as OFDM . The random binary data was generated and transmitted via the dispersive channel with using additive white Gaussian noise (AWGN) channel model. We also analyze several aspects on the performance of the system was which valuated by calculating the number of bit errors for several value of signal to noise ratio (SNR).As compared to the conventional method we also compare so that we can improve the power of the system.

In future we apply the scheme with the real time simulation environment so that we can deduce several performance implications.

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