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PAPR Reduction in DWT Based OFDM System Adopting DAPSK Modulation Scheme

Akshita, Vinay Thakur

***Abstract*— In this manuscript, a discrete wavelet transform (DWT) based OFDM (orthogonal frequency division multiplexing) system, which adopts differential amplitude phase shift keying (DAPSK) as its modulation scheme is discussed. In addition to this, the performance of such OFDM system is evaluated in terms of the bit error rate (BER) and peak average power ratio (PAPR) in the presence of Additive white Gaussian noise (AWGN) and multipath fading as channel impairments using the MATLAB simulation. The simulation responses of the DWT based OFDM system demonstrates significant improvement in terms of the BER and PAPR as compared to that of the DFT and DCT based system.**

***Index Terms*— BER, DCT-OFDM, DFT-OFDM, DWT-OFDM, PAPR.**

I. Introduction

The broadband wireless services which require high data-rates and signal quality depend on the wireless channels. At the same time, the wireless channels have impairments such as fading, shadowing and multi-user interference which highly degrade the system performance. However, in order to accomplish the increased demand for flexible high data-rate services for users, it is required to improve the system performance in terms of the fading, shadowing and multi-user interference. With the aforementioned issues taken into account, the OFDM system is of the prime importance.

OFDM is a multicarrier modulation scheme, which provide high performance over multipath environments and is used in many wireless applications. In OFDM systems, the data is transmitted using several narrow-band orthogonal sub-carriers [1]. Conventionally, OFDM is implemented using Discrete Fourier transform (DFT) and Discrete Cosine transform (DCT), which usually adopt binary phase shift keying (BPSK)/quadrature phase shift keying (QPSK) or quadrature amplitude modulation (QAM) scheme. In addition to this, OFDM is robust against narrowband interference because such interference affects only a small percentage of the subcarriers, which enhance the solidity against frequency-selective fading. The data to be transmitted is divided into many lower-speed bit streams and modulated.

In this manuscript, we have discussed the performance of OFDM system using 1) DCT, 2) DFT and, 3) DWT. Moreover the performance (in terms of BER and PAPR) of OFDM system using afore mentioned techniques are compared using the MALAB simulation tool. In [2], it has been discussed that the DCT (Discrete Cosine Transform) is a real transform, which transforms a sequence of real data points into its real spectrum and therefore avoids the problem of redundancy. However, the DFT (Discrete Fourier Transform) transforms a complex signal into its complex spectrum. If, the signal is real, half of the data is redundant. Moreover, in time domain, the imaginary part of the signal is all zero, rather the real part of the spectrum is even symmetric and imaginary part odd in frequency domain [2]. On the other hand, DWT (Discrete Wavelet Transform) returns a data vector of the same length as the input is. Usually, this vector many data are almost zero which corresponds that it decomposes into a set of wavelets (functions) that are orthogonal to its translations and scaling [3].

The remainder of the paper is organized as follows. Section II describes the related work of OFDM system in which we have discussed the OFDM model, factors affecting the OFDM system and different techniques for reducing the PAPR in the OFDM system. Section III explores the performance of OFDM system using the DCT, DFT and DWT techniques. Finally, Section IV concludes the work with future considerations.

Akshita, *Electronics and Communication, Sri Sai University Palampur M.tech.*
Vinay Thakur, *Electronics and Communication, Sri Sai University Palampur,Assistant Professor.*

II. Related Work

A. OFDM Model

The OFDM signal generated by the system is at baseband. In order to generate a radio frequency (RF) signal at the desired transmit frequency filtering and mixing is required. OFDM allows for a high spectral efficiency as the carrier power and modulation scheme is individually controlled for each carrier. However in broadcast systems the carrier power and modulation scheme is fixed due to the one-way communication. The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers as shown in Fig. 1. In OFDM system different modulation techniques have been used such as QAM (quadrature amplitude modulation technique which conveys data by modulating the amplitude of two carrier waves), BPSK, and DAPSK. In QAM, the resulting waveform is the combinations of both ASK and PSK techniques. BPSK is the modulation scheme,in which the phase of a carrier is changed in accordance with the digital modulation. However, the OFDM system is shown in Fig. 1 along with its transmitter and receiver specifications.

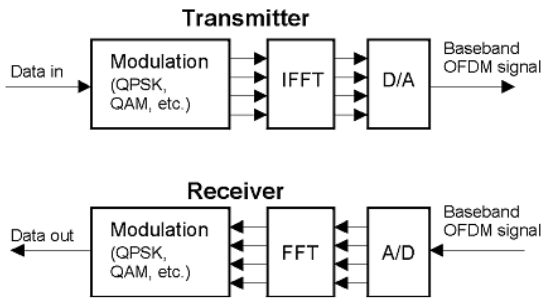

Fig. 1 OFDM transmitter and receiver.

B. *Factor affecting the system performance*

a. Inter-symbol Interference (ISI)-: ISI is a form of distortion of a signal in which one symbol interferes with all resultant symbols. It is the unwanted phenomenon as the previous symbols have similar effect as noise thus it makes the communication less reliable. ISI is caused by the multipath propagation and band limited channels. As, in the multipath propagation the wireless signal from a transmitter reaches the receiver via many different paths. This is caused by reflection, refraction and atmospheric effects such as atmospheric ducting and ionosphere reflection. On the other hand, propagating a signal through band limited channels result in the removal of frequency components above this cut off frequency. In addition to this, the amplitude of frequency components below the cut off frequency may also be attenuated by the channel.

b. Inter-carrier Interference (ICI)-: The presence of Doppler shifts, frequency offsets and phase offsets in an OFDM system cause loss in orthogonality of the sub carriers. As a result, the ICI interference is observed in the sub carriers. To increase the data rate in OFDM system, the numbers of OFDM symbols have been increased. As the spacing between the sub carriers increases, the number OFDM symbols reduces, which makes the OFDM system more sensitive to ICI.

c. Bit Error Rate (BER)

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been changed by interference, noise, bit synchronization errors and distortion. The BER is the number of bits errors divided by the total number of transferred bits. The bit error probability (ρ_e) is the expectation value of the BER. In communication system, the receiver side BER is affected by transmission channel distortion, noise, bit synchronization problem, interference, attenuation, and wireless multipath fading. The BER is improved by selecting strong signal strength, by selecting robust and slow modulation scheme or line coding techniques and by applying channel coding techniques such as redundant forward error correction codes.

d. Peak to Average Power Ratio (PAPR)

In OFDM systems due to the presence of large number of independently modulated sub carriers, the peak value of the OFDM system can be very high as compared to the average of the whole system. This ratio of peak to average power value is termed as PAPR. The coherent addition of N number of signals of same phase produces a peak which is *N* times the average signal. The major disadvantages of PAPR are increased in the complexity of converters and reduce the efficiency of amplifiers. There are number of techniques to deal with the problem of PAPR. Some of them are amplitude clipping, clipping and filtering, coding, selected mapping, partial transmit sequence and interleaving. These techniques are used to reduce the problem of PAPR at the expense of transmit power increase, bit error rate increase, data rate loss increase and computational complexity increase.

C. *PAPR Reduction Techniques*

a. DCT-OFDM
b. DWT-OFDM
c. DFT-OFDM

a. DCT Based OFDM System (DCT-OFDM)

Instead of using complex exponential functions, cosinusoidal functions are used as orthogonal basis functions to implement multi-carrier scheme, which is synthesized using DCT [4, 5]. For fast implementation algorithms, DCT provides fewer computational steps as compared to that of the FFT based OFDM. The effect of carrier frequency offset (CFO) introduces ICI in both the DFT-OFDM and DCT-OFDM. The sequence of *N* complex numbers such as $x_0 \ldots x_{N-1}$ is transformed into the sequence of *N* complex numbers such as $X_0 \ldots X_{N-1}$, respectively, uses the DFT according to the Eq. (1).

$$X_{k=}1/\sqrt{N}\,\sum_{n=0}^{N-1} xn\, e^{-2\pi j/N} k_n,\ k = 0, \ldots, N-1 \quad (1)$$

Further, the Inverse Discrete Fourier Transform (IDFT) is given by Eq. (2)

$$x_n = 1/\sqrt{N}\,\sum_{k=0}^{N-1} xk \qquad n=0,\ldots,N-1 \quad (2)$$

where *n = 0... N-1*

The complex numbers X_k represent the amplitude and phase of the different sinusoidal components of the input signal x_n. The DFT computes the X_k from the x_n while the IDFT computes the x_n as a sum of sinusoidal components $(\frac{1}{N})X_k e_N^{-2\pi ikn}$ with frequency $\frac{K}{N}$ cycles per sample. A single cosinusoidal function is a set of cos ($2\pi n F_\wedge t$) is used as the orthogonal basis to implement multicarrier modulation in DCT-OFDM [6, 7]. The minimum $F_\wedge$ required to satisfy Eq. (3) is 1/2T Hz.

$$\int_0^T \sqrt{2/T}\ \cos(2\pi\ f_\wedge\ t)\ \sqrt{2/T}\cos(2\pi m F_\Delta t)\ dt = \begin{cases}1, k = m\\ 0, k \neq m\end{cases} \quad (3)$$

The continuous-time output signal of a DCT based OFDM system can be written as

$$X(t)=\sqrt{\frac{2}{N_s}}\sum_{n=0}^{N_s-1} d_n\,\beta_n \cos(\frac{n\pi t}{T_s}) \quad (4)$$

where $d_0, d_1 \ldots\ D_{Ns-1}$ are N_s independent data symbols obtained from a modulation constellation and

$$\beta_n = \begin{cases} \frac{1}{\sqrt{2}}.n = 0 \\ 1 \quad n = 1, 2 - -N_s - 1\end{cases} \quad (5)$$

The BER performance of DCT-OFDM is better than DFT-OFDM, the signal energy in DCT is concentrated in a few low-index DCT coefficients, while the remaining coefficients are zero or are negligibly small. Moreover, it has been discussed that the DCT is close to optimal in terms of energy-compaction capabilities. A zero-padding guard-interval scheme is used in DCT-OFDM system. The zero-padding scheme eliminates ISI, which improves transmission efficiency. In DFT-OFDM, the zero-padded DFT-OFDM achieves the better BER performance than the cyclic prefix DFT-OFDM.

b. Wavelet Based OFDM System (DWT-OFDM)

This section discusses the alternative way to implement OFDM using DWT [8]. In DWT-OFDM, the time-windowed complex exponentials are replaced by wavelet “carriers", at different scales *(j)* and positions on the time axis *(k)*. These functions are generated by the translation and dilation of a unique function, called "wavelets mother" and denoted by ψ. The wavelet carriers exhibit better time-frequency localization than complex exponentials [8] while DWT-OFDM implementation complexity is comparable to that of FFT- OFDM. The key point ‘orthogonality’ is achieved by generating members of a wavelet family, according to Eq. (6)

$$\psi_{j,k}(t) = 2^{-j/2}\psi(2^{-j}t - k) \qquad (6)$$

To obtain finite number of scales, scaling function $\psi(t)$ is used. DWT-OFDM symbol is considered as the weighted sum of wavelet and scale carriers, as expressed in Eq. (7), which is close to the Inverse Wavelet Transform (IDWT).

$$\{\psi_{j,k}(t), \psi_{m,n}(t)\} = \begin{cases} 1, if\ j = m \quad , k = n \\ 0,\ otherwise \end{cases} \qquad (7)$$

The data symbols are seen by IDWT modulator as sequence of wavelet $w_{j,k}$ and approximation coefficients $a_{j,k}$. According to Eq. (6) J is the scale with poorest time resolution and best frequency localization of the carriers. For computing IDWT, Mallat’s algorithm based on filter bank is used instead of Eq. (8).

$$s(t) = \sum_{jsj} \sum_k e_{j,k}(t)\psi_{j,k} + \sum_k a_j, k\varphi_{j,k}(t) \qquad (8)$$

At the output of the filter discrete version of DWT-OFDM symbol is obtained, with impulse response of filters (low-pass and high-pass) decided by the wavelet mother.

c. DFT-Based OFDM (DFT OFDM)

In the conventional OFDM systems, the digital modulation and demodulation is realized with the IDFT and DFT, respectively. OFDM employs N separate subcarriers to transmit data instead of one main carrier. The input data is grouped into a block of N bits, where $N = N_s \times N_n$ where N_s is the number of independent data symbols and N_n is the number of bits used to represent a symbol for each subcarrier. In order to maintain orthogonality between the sub-carriers, these are required to be spaced apart by an integer multiple of the subcarrier symbol rate R_s. The subcarrier symbol rate is related to overall code bit rate R_c of the entire system by $R_s = R_c / N$. The output signal of an OFDM can be written as.

$$X(t) = \sum_{n=o}^{N_s-1} C_k e^{2\pi(n-\frac{N_s}{2})\frac{t}{T_s}} \qquad (9)$$

where C_k the complex representations of the subcarrier symbols and T_s is the symbol period.

III. Results and Conclusion

There are different channels which are used for the transmission the data in the OFDM systems. In this section we have discussed the performance of the OFDM using a) Additive white Gaussian noise (AWGN) channel and b) Flat Fading channel.

A. AWGN channel

It is a basic noise model used in the information theory to mimic the effect of many random processes that occur in nature. The 'Additive' means the noise is added to any noise that is intrinsic to the information system. Further ‘White' refers to idea that it has uniform power across the frequency band for the information system which is an analogy to the color white and has uniform emissions at all frequencies in the spectrum. The ‘Gaussian' corresponds to a normal distribution in the time domain with an average time domain value of zero.

B. Flat fading channel

It is amplitude varying channel and narrowband channel. In this channel, the coherence bandwidth of the channel is larger than the bandwidth of the signal. The performance of DCT, DFT and DWT-OFDM in terms of BER is demonstrated in Fig. 2, which reveals that in the given range of SNR such as 0 – 30, the DWT-OFDM offer high BER as compared to that of the DCT and DFT-OFDM.

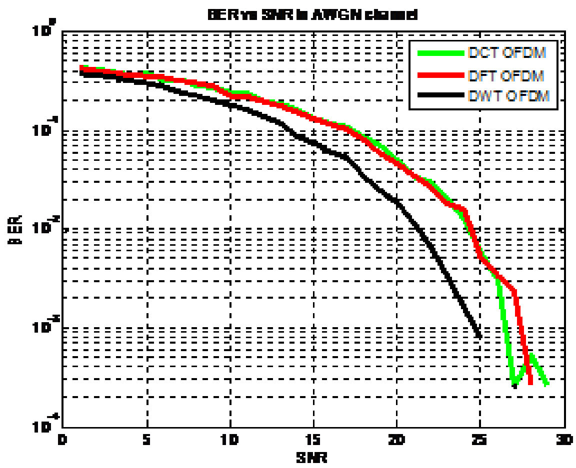

Fig. 2 Comparison of BER v/s SNR in AWGN channels using DCT, DFT and DWT-OFDM.

After the calculation of the BER of system then PAPR of the received signal is calculated. This PAPR is of DCT, DFT, and DWT OFDM. Fig. 3 demonstrates that at low SNR (~ 20), all the three techniques (i.e. DCT, DFT and DWT) offer significantly equal values of BER. On the other hand, at high SNR, DCT and DFT-OFDM provide equal values of BER while DWT-OFDM demonstrates significantly higher value of BER.

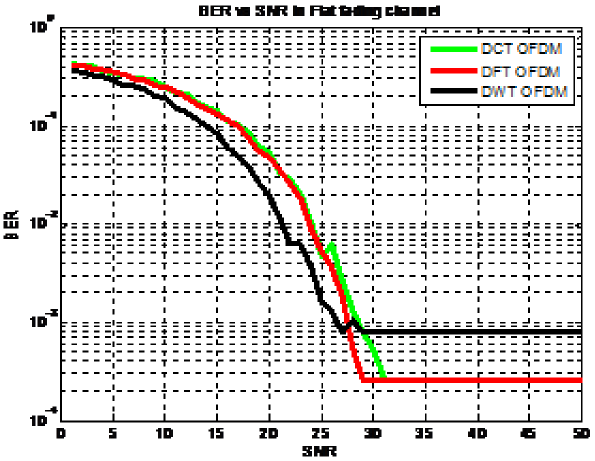

Fig. 3 Comparison of BER v/s SNR in Flat fading channel using DCT, DFT and DWT-OFDM.

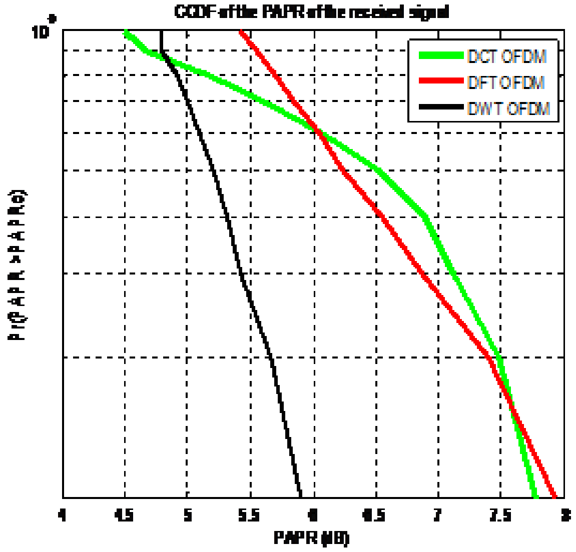

Fig. 4 Comparison of PAPR for the received signal in DCT, DFT and DWT-OFDM.

It is well known that the prime limitation of the OFDM system is the high PAPR [9, 10]. Therefore in order to reduce the PAPR we have used different techniques such as DCT, DFT and DWT-OFDM in the OFDM systems. Further Fig.4 demonstrates that the DWT-OFDM gives significant PAPR as compared to other two techniques.

IV. CONCLUSION

In this paper we are studying various OFDM PAPR reduction techniques like DCT-OFDM, DWT-OFDM, and DFT-OFDM. But the simulation results shows that DWT-OFDM provides better results than the other techniques by using DAPSK modulation technique. The performance of the system was evaluated in the presence of AWGN and multipath fading as channel impairments. The results show the superiority of the DWT based OFDM system when compared to a DFT and DCT based system. For future considerations we have focused on increasing the BER in the DWT-OFDM at lower SNR also.

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Ms. Akshita has completed B.Tech in ECE from Kurukheshtra University in 2012. She is currently pursuing her M.Tech from Sri Sai University, Palampur. Interests of area are OFDM and wireless networks.

Mr. Vinay Thakur has completed his B.Tech in Electronics and Communication Engineering from CTIEMT (2005-09). He has completed M.Tech in Electronics and Communication Engineering from Lovely Professional University, Jalandhar. He is working as Assistant Professor in Sri Sai University, Palampur. His area of interest is DIP. He has published papers in the various international journals and also in international and national conferences.