

Use of PAPR Control and Sub-sliding Windowing Techniques in the improvement of the Bit Error Rate in IFFT-FFT and IDWT-DWT Based OFDM Systems

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Abstract— the paper aims at providing an efficient MATLAB Code in obtaining significant reduction in the Bit Error Rate (BER) Curve for two different Orthogonal Frequency Division Multiplexing (OFDM) Systems: FFT-IFFT OFDM System and an IDWT-DWT OFDM System, based on the knowledge obtained from Peak to Average Power Ratio (PAPR) Control and Sub-Sliding Windowing techniques. While the IFFT System has been BPSK Modulated, the IDWT system has been QAM Modulated. These modulation techniques are used in keeping with the state-of-the-art wireless communication systems and services.

Index Terms— Fast Fourier Transformations (FFT), Inverse Fast Fourier Transformations (IFFT), Peak to Average Power Ratio (PAPR), Sub-Sliding Windowing techniques, Discrete Wavelet Transformations (DWT), Inverse Discrete Wavelet Transformations (IDWT), BPSK, QAM, MATLAB 2012(B), ISI, ICI.

1 INTRODUCTION

With an increase in the demand for faster and more reliable communication systems, efficient Multiple Access Techniques like Orthogonal Frequency Division Multiple Access (OFDMA) techniques have become the need of the hour. OFDMA is preferred to other Multiple Access techniques like CDMA, TDMA or FDMA for the reason that it is free from the adverse effects of Inter-symbol Interference (ISI) and Inter Carrier Interference (ICI) and hence is best suited for wireless broadband services like WiMax and WiBro. [6] OFDM allows the high rate data stream to be broken into parallel low rate data streams which are then transmitted over the channel using sub-carriers that are "orthogonal" or statistically independent to each other. This allows the overlapping of the subcarrier frequencies in the transmitter section of the OFDM while they can be extracted in the receiver section without any interference, thereby increasing the spectral efficiency of the system.

Due to the use of AWGN channel as a communication channel, the subcarriers are exposed to flat fading which can be corrected by using a single tap delay line filter. Because of the existence of orthogonality among the carriers with respect to one another, the system is free from any Inter Carrier Interference (ICI) as seen in CDMA and FDMA systems even without the use of a guard-band. But studies have concluded in the fact that all kinds of OFDM systems are susceptible to signal degradation due to Doppler shifts between transmitter and receiver, phase noise due to channel impairment, the inability of the system to sample its bits due to signal amplitude reduction and other power related constraints.

Hence the central theme of the paper is to re-multiply the degradation factors to a complex baseband signal to gain improvement in the convergence of the BER Plot on a semi-log graph.

2 DESCRIPTION OF THE OFDM SYSTEMS AND THE CONTROL TECHNIQUES

2.1 FFT-IFFT based OFDM System

An FFT-IFFT Type OFDM System is the most conventional forms of OFDM system where The data symbols (d_n) are first assembled into a group of block size N and then modulated with complex exponential waveform $\{\phi_k(t)\}$ After modulation they are transmitted simultaneously as transmitter data stream.

Mathematically, an IFFT-FFT Based OFDM System can be expressed as:

$$c(t) = \sum_{n=0}^{N-1} s_n(t) \sin(2\pi f_n t)$$

Where:

- $S_n(t)$ = symbols mapped to chosen constellation (BPSK/QPSK/QAM etc.,)
- f_n = orthogonal frequency

Owing to the fact that the OFDM signal ($c(t)$ in the equation above) is in time domain, IFFT convenient to be used in the transmitter section where the frequency domain samples are converted to time domain samples. IFFT/FFT equation comes handy in implementing the conversion process from time to frequency to time domain where elimination of the individual sinusoidal multipliers are required in the transmitter/receiver side. In the diagrammatic block representation given below; the critical importance of the removal of sinusoidal frequencies can be understood.

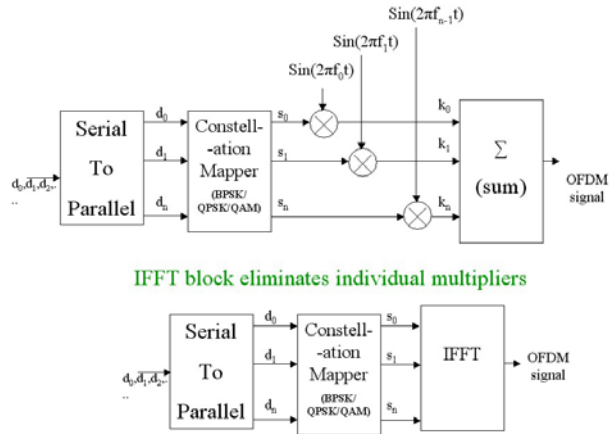


Fig 1: A Standard OFDM Transmitter transformed into an FFT-IFFT Based OFDM Transmitter

In the system, the bits to be transmitted across the channel are first encoded in the coder section and then fed to the serial-to-parallel converter where 'N' parallel bits are obtained at the output of the SIPO.

The output obtained at the SIPO is then fed to the N-IFFT; at the output of which is fed the cyclic prefix. The cyclic prefix helps in the process of circular convolution. Circular convolution, also known as cyclic convolution of two aperiodic functions (i.e. Schwartz functions) occurs when one of them is convolved in the normal way with a periodic summation of the other function. That situation arises in the context of the Circular convolution theorem. The output of the IFFT is then fed to the PISO, DAC and RF amplifier and after power control is transmitted through the transmitting antenna.

2.2 IDWT-DWT based OFDM System

Discrete Wavelet Transformations are preferred to Fast Fourier Transformations for the simple reason that they not only orthogonalise the bit stream but also normalise it to reduce redundancy. Other than making the signal statistically independent, it also makes use of the Nyquist frequency to achieve normalization. A Two dimensional Discrete Wavelet Transformer can be pictorially explained as:

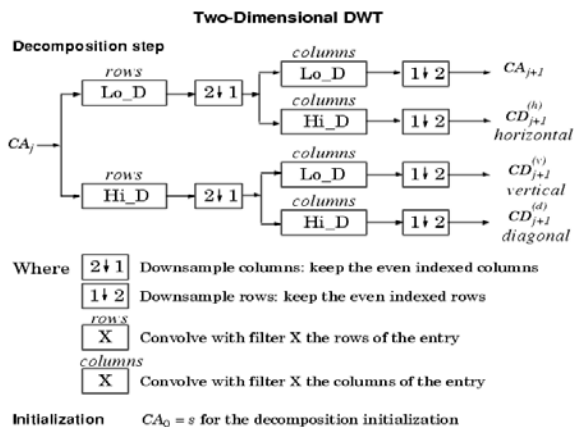


Fig 2: Decomposition and Down-sampling process in a 2D-

DWT

After Quadrature Modulation and addition of the vector, the decomposition Initialization - CA is characterised by an inversion in the signs of the bits and a change from a serial to a parallel matrix. The signal is then up-sampled and filtered by the LPF coefficients or namely as approximated coefficients.

The modulated signals perform circular convolution with LPF filter whereas the HPF filter also performs the convolution with zeroes padding the output signal CD. HPF filter contains detailed coefficients or wavelet coefficients. Different wavelet families have different filter length and values of approximated and detailed coefficients. Both of these filters have to satisfy orthonormal bases in order to operate as a wavelet transform pair. In the transmitter part, this signal is simulated using MATLAB command $[Xk] = idwt(CA, CD, wv)$ where wv is the type of wavelet family. On the other hand, the reverse process is simulated using $[ca, cd] = dwt(Uk, wv)$ in the receiver.

The CA signal will be processed to the QAM demodulator for data recovery. However, the CD signal is discarded because it does not contain any useful information.

The block diagram of a DWT based OFDM system could be represented as:

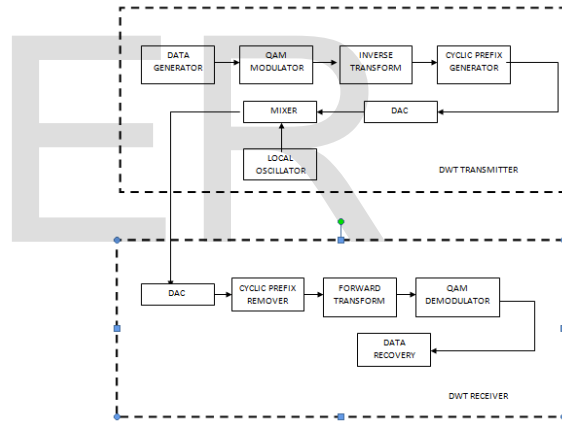


Fig 3: An IDWT-DWT based OFDM system

2.3 Use of Sub-Sliding Windowing Technique in improving the BER of an OFDM System

The sub-sliding windowing technique suggests that a single acknowledgement can be used to indicate the reception of multiple packets between two host computers in a TCP-IP Layer protocol.

The OFDM system being more sensitive to frequency error than other sub-carrier systems, a frequency offset is likely to be produced due to the following reasons:

- Doppler Shift arising out of the relative motion between Transmitter and Receiver
- Phase noise due to channel impairments of neighbouring carriers

Thus the degradation function in term of the frequency offset (Δf) can be mathematically expressed as:

$$SNR_{in} (dB) \approx \frac{10}{3 \ln 10} (\pi T f_{\Delta})^2 \frac{E_s}{N_0}$$

Hence with the re-multiplication of the factor of 10/3 and π to the baseband signal, the frequency offset can be removed and a better convergence curve for BER can be created.

2.4 Use of PAPR Control Technique in improving the BER of an OFDM System

The PAPR or the Peak to Average Power Ratio Control method suggests that due to the overlapping of the carriers in the transmitter section in the OFDM, the signal may exhibit a high instantaneous peak with respect to an average signal level causing incompatibility between the DAC and the ADC. Reduction in the efficiency of the RF amplifier would mean a higher Power Output Back-off and degradation in the signal arising due to the non-linearity of the RF amplifier. Efficient control of the PAP would involve the use of forward error correction codes or golay code as scrambles for the OFDM symbols. Another effective method, as suggested in this paper could be the re-multiplication of the variance factor to the complex baseband signal which could be mathematically represented as:

$$\tilde{s}(t) = x(t) + jy(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} A_k e^{j2\pi(k/T_s)t}$$

Where

- A_k is the complex data of the k th sub-carrier
- T_s is the OFDM symbol period

For a large value of N number of subcarriers, the mean for the Gaussian distributed values is taken as 0 and the variance is taken as $1/2$.

3 PROCEDURES FOLLOWED FOR CODING AND RESULTS OBTAINED

3.1 Steps followed for coding a BPSK Modulated IFFT-FFT based OFDM System

- Define FFT size
- Define the number of data subcarriers
- Define the number of bits per OFDM symbol (same as the number of subcarriers for BPSK)
- Define the number of symbols

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- Set the bit to noise ratio parameters
- Convert to symbol to noise ratio

- Define a for loop from 1 to the Length of Bit to Noise ratio
- Set the Transmitter by:
 - Creating a random function for creating random 1's and 0's
 - Write the modulation function formula for BPSK modulation
 - Group the modulation function into streams multiple symbol
 - Assign the modulated symbols to subcarriers from [-26 to -1, +1 to +26]
 - Normalize the power of symbol about to be transmitted to 1
 - Append cyclic prefix onto the symbol to be transmitted
 - Concatenate the multiple symbols to form a long vector
 - Define a function to create Gaussian noise of unit variance, 0 mean
 - Add noise to the term to keep an account of the energy wasted due to cyclic prefix
- Set the Receiver by:
 - formatting the received vector into symbols
 - removing cyclic prefix
 - convert the symbols in time domain to frequency domain
 - Carry out the process of BPSK demodulation
 - Reconvert modulated values into bits
 - Define a function to count the errors
 - End the FOR Loop
 - Define a function involving the use of Sub-sliding Windowing technique used to improve the BER
 - multiplying variance with Simulated Bit Error Rate to view a Peak to Average Power Ratio Controlled BER Curve
 - Define a function for a Theoretical BER curve to serve as a reference.
 - Define semilogies to plot the graph and also set up the parameters for the grid

A part of the MATLAB code used in creating the system is:

```
% BPSK demodulation
% +ve value -> 1, -ve value -> -1
ipModHat = 2*floor(real(yMod/2)) + 1;
ipModHat(find(ipModHat>1)) = +1;
ipModHat(find(ipModHat<-1)) = -1;

% converting modulated values into bits
ipBitHat = (ipModHat+1)/2;
ipBitHat = reshape(ipBitHat.', nBitPerSym*nSym, 1).';

% counting the errors
nErr(ii) = size(find(ipBitHat -
```

```
ipBit),2);
```

```
end
```

```
simBer_sliding =
nErr/(nSym*nBitPerSym);
bit_error_rate_parp =
(1/2)*sqrt(simBer_sliding/10);
%multiplying variance with Simulate Bit
Error Rate Slide
theoryBer =
(1/2)*erfc(sqrt(10.^(EbNo/10)));
```

```
close all; figure
```

3.2 Steps followed for coding a QAM Modulated IDWT-DWT Based OFDM System

- Define the Size of signal constellation
- Define the Number of bits per symbol
- Number of symbols used /bits to process
- Set the Oversampling rate at 1
- Define the FFT size
- Define the number of data subcarriers to be used
- Set QAM symbols per OFDM symbol with a value same as that of the number of subcarriers used
- Set the Bit to Noise value parameters
- Define a for loop from 1 to the Length of Bit to Noise ratio
- Define a Signal Source by creating a binary data stream as a column vector.
- Perform the function of Bit-to-Symbol Mapping
- Convert the bits in x into k-bit symbols.
- Perform Modulation using 16-QAM.
- Group the bits into multiple symbols
- After grouping, use the function of Inverse Discrete Wavelet Transformation
- Transmit the signal over the AWGN Channel
- At the receiver end, use the function of Discrete Wavelet Transformation
- Perform the function of Demodulation by Demodulating the signal using 16-QAM.
- Perform Symbol-to-Bit Mapping by undoing the bit-to-symbol mapping performed earlier.
- Convert the integers to bits.
- Convert z from a matrix to a vector.
- Go on for BER Computation by compare x and z to obtain the number of errors and the bit error rate.
- Defining the baseband signal by adding x and z
- Multiply Variance with EbNo Values to achieve PAPR control and feed it to the base band signal using the erfc function

- Make the use of pi (Π) as a shift/sliding factor
- End the FOR Loop
- Define a function involving the use of Sub-sliding Windowing technique used to improve the BER
- multiplying variance with Simulated Bit Error Rate to view a Peak to Average Power Ratio Controlled BER Curve
- Define a function for a Theoretical BER curve to serve as a reference.
- Define semilogies to plot the graph and also set up the parameters for the grid

A part of the MATLAB Code used in coding the system is given as:

```
%% Modulation
% Modulate using 16-QAM.
y = modulate(modem.qammod(M),xsym);
xF = reshape(y,k,length(y)/k).';%
grouping into multiple symbol
xF1=zeros(size(xF));
xt = (idwt(xF,xF1,'haar')).';
%% Transmitted Signal
%% Channel
% Send signal over an AWGN channel.
%% Received Signal
[yF1,yF2] =dwt(xt,'haar');
S=[yF1,yF2];
%% Demodulation
% Demodulate signal using 16-QAM.
zsym = demodulate(modem.qamdemod(M),S);
zsym1=zsym.';
%% Symbol-to-Bit Mapping
% Undo the bit-to-symbol mapping per-
formed earlier.
z1 = de2bi(zsym1,'left-msb'); % Convert
integers to bits.
% Convert z from a matrix to a vector
z = reshape(z1.',prod(size(z1)),1);
%% BER Computation
% Compare x and z to obtain the number
of errors and
% the bit error rate.
basebandsig=x(ii)+z(ii); %Defining the
baseband signal
bit_error_rate_parp =
(1/2)*erfc(sqrt(basebandsig.^(EbNo/2)))
; %multiplying variance with EbNo
bit_error_rate_subslide=3.34*(erfc(sqrt
(3.14*basebandsig.^(3.14*EbNo/10))));
%Use of pi as a shift/sliding factor
end
theoryBer =
(1/2)*erfc(sqrt(10.^(EbNo/10)));
```


close all; figure

3.3 Parameters used and simulation curve obtained for a BPSK Modulated IFFT-FFT OFDM System

Parameters used are given as:

FFT Size	64
Number of Data Subcarriers	52
Number of Bits per OFDM Symbol	52
Number of Symbols used	10 ⁴
Bit to Noise Ratio	[1:10]

The simulation curve obtained for the code mentioned above is given as:

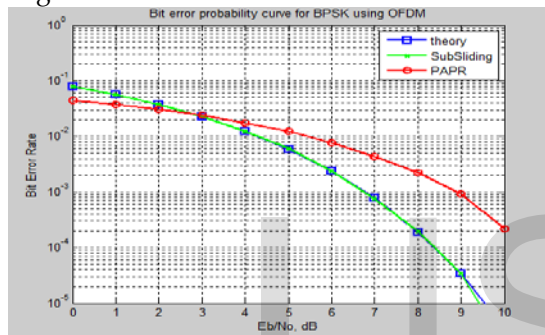


Fig 4: BER Probability Curve for a BPSK Modulated OFDM System using IFFT and FFT

It can be inferred from the plot that the BPSK system is not affected by the non-linearity of the RF Amplifier as much as it is affected by the Doppler shift or the phase noise arising out of Inter Carrier Interference. Hence sub-sliding technique is a better approach in improving the BER convergence curve because on re-multiplication of the variance factor of 1/2, the PAP ratio for the system increases, causing it to be more prone to error.

3.4 Parameters used and the simulation curve obtained for the QAM Modulated IDWT-DWT OFDM System

The parameters used are given as:

FFT Size	64
Number of Data Subcarriers	32
Number of Bits per OFDM Symbol	32
Number of Symbols used	10 ⁴
Bit to Noise Ratio	[-3:20]
Channel Used	AWGN

The simulation curve obtained for the curve mentioned above is given as:

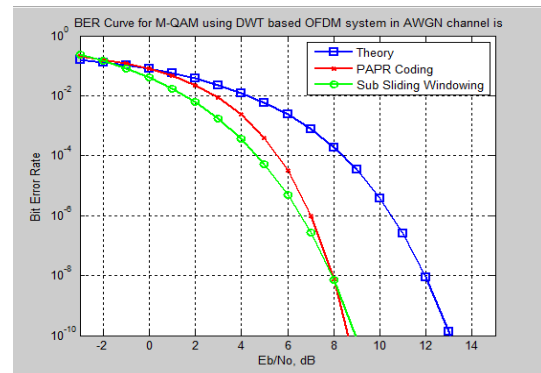


Fig 4: BER Probability Curve for a QAM Modulated OFDM System using IDWT and DWT

The plot obtained clearly suggests that both the PAPR Control Technique and the Sub Sliding Windowing technique are helpful in bringing improvement to the convergence curve of the BER plot for the OFDM system. It also proves that the signal is susceptible to the increase in the complexity of the DAC and the ADC as well as the Inter Carrier Interference and the phase noise. The sub-sliding technique is a more reliable method in reducing the number of erroneous bits in the transmitted signal. Overall, both methods are efficient.

4 CONCLUSIONS

It can be concluded that the IDWT-DWT system of OFDM has better control over the IFFT-FFT system of OFDM. Use of BER controlling techniques like the PAPR Control Technique and the Sub-sliding Windowing technique can further find use in improving the convergence curve for the BER plot; making the OFDM system best suited for Wireless Broadband Communication Systems and can also be used as a Multiple Access Technique (OFDMA) in 4G Communications where these two techniques can find use making the system reliable and efficient.

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