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Peak to Average Power Reduction using Radix-2 Decimation in Frequency Fast Fourier Transform in OFDM System

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is used for wideband data communications over mobile radio FM channels, High-bit-rate Digital Subscriber Lines (HDSL, 1.6Mbps), Asymmetric Digital Subscriber Lines (ADSL, up to 6Mbps), Very-high-speed Digital Subscriber Lines (VDSL, 100Mbps), Digital Audio Broadcasting (DAB), and High Definition Television (HDTV) terrestrial broadcasting. The OFDM system has a high peak-to-average power ratio (PAPR) that can cause unwanted saturation in the power amplifiers. In order to avoid nonlinear distortion, highly linear amplifiers are required which cause a severe reduction in power efficiency. In this paper, a new scheme for PAPR reduction is proposed using Radix-2 Discrete in Frequency (DIF) Fast Fourier Transform (FFT). In proposed scheme we have used signal processing technique to reduce PAPR. The proposed scheme provides 3.3dB performance improvement in PAPR to than standard OFDM system as simulated in MATLAB.

Keywords: OFDM (Orthogonal Frequency Division Multiplexing), PAPR (Peak to Average Power Ratio), DIF(Decimation in Frequency), FFT(Fast Fourier Transform)

Introduction

Wireless Communication is a rising field which has been on tremendous growth from last several decades. The upcoming 4G (Fourth Generation) mobile communication systems are designed to solve problems of 3G (Third Generation) systems and to provide a wide variety of new services, from high-quality voice to high-definition video to high-data-rate wireless channels. One of the terms used to describe 4G is MAGIC—Mobile Multimedia, Anytime Anywhere, Global Mobility Support, Integrated Wireless Solution, and Customized Personal Service. Systems based on 4G, that is, cellular broadband wireless access systems have been appealing much interest in the mobile communication area. The 4G systems not only will support the next generation of mobile service, but also will support the fixed wireless networks. The rising demand for very high rate wireless data transmission, invites new technologies in 4G which make use of the available resource in the most efficient way. Key objectives are spectrum efficiency (bits per second per Hertz), strength against multipath propagation, range, power consumption, and implementation complexity. OFDM supports such high data rates with sufficient robustness to radio channel deteriorations and becoming the chosen digital modulation technique for wireless communications. It may also be termed as a special form of multi carrier modulation technique which is used to generate waveforms that are mutually orthogonal. The OFDM system has a high peak-to-average power ratio (PAPR) that can cause unwanted saturation in the power amplifiers, leading to in-band distortion and out-of-band radiation. There are several techniques to reduce the PAPR in OFDM transmission system. All PAPR reduction techniques have some advantages and disadvantages. There are many issues to be considered before using the PAPR reduction techniques in a digital communication system. These issues include PAPR reduction capacity, power increase in transmit signal, BER increase at the receiver, loss in data rate, computational complexity increase and so on.

Standard OFDM

The basic principle of OFDM is to split a high rate input data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers [1]. ISI is eliminated almost completely by adding a guard interval at the beginning of each OFDM symbol [2]. However, instead of using an empty guard time, this interval is filled with a cyclically extended version of the OFDM symbol. This method is used to avoid ICI.

A. OFDM TRANSMITTER STRUCTURE

Fig. 1 shows a basic OFDM transmitter structure. The serial input data stream is divided into frames of Nf bits. These Nf bits are arranged into N groups, Number of carriers are represented by N. The number of bits in each of the N groups determines the constellation size for that particular subcarrier. OFDM can be considered as N independent QAM channels, each having a different QAM constellation but each operating at the same symbol rate 1/T. After signal mapping, N complex points are obtained.

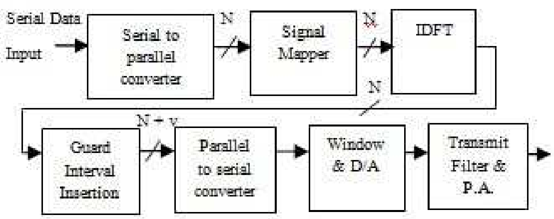

Fig. 1 Block diagram of an OFDM transmitter

These complex points are passed through an IDFT block. Cyclic prefix of length v is added to the IDFT output in order to combat with ICI and ISI. After Parallel–to- Serial conversion, windowing function is applied. The output is fed into a Digital-to-Analog converter operating at a frequency of N/T. Finally transmit filter is applied in order to provide necessary spectrum shaping before power amplification. Let denote $[D_0, D_1\ldots D_{N-1}]$ data symbols. Digital signal processing techniques, rather than frequency synthesizers, can be deployed to generate orthogonal sub-carriers [3]. The DFT as a linear transformation maps the complex data symbols $[D_0, D_1\ldots D_{N-1}]$ to OFDM symbols $[d_0, d_1\ldots d_{N-1}]$ such that

$$d_k = \sum_{n=0}^{N-1} D_n e^{j2\pi n\frac{k}{N}} \qquad (1)$$

The linear mapping can be represented in matrix form as:

$$\bar{d} = \bar{W}\bar{D} \qquad (2)$$

Where

$$\bar{W} = \begin{bmatrix} 1 & \cdots & 1 & 1 \\ \vdots & W & \ddots & \vdots \\ 1 & W^{N-1} & \cdots & W^{N(N-1)} \end{bmatrix} \qquad (3)$$

and

$$W = e^{j2\pi/N} \qquad (4)$$

$\bar{W}$is a symmetric and orthogonal matrix. After FFT, a cyclic pre/postfix of lengths k_1 and k_2 will be added to each block (OFDM symbol) followed by a pulse shaping block. Proper pulse shaping has an important effect in improving the performance of OFDM systems in the presence of some channel impairments. The output of this block is fed to a D/A at the rate of f_s, and low-pass filtered. A basic representation of the equivalent complex baseband transmitted signal is

$$x(t) = \sum_{n=0}^{N-1} D_n e^{j2\pi nt\frac{f_1}{N}} \qquad \text{for} \qquad -\frac{k_1}{f_s} < t < \frac{N+k_2}{f_s} \quad (5)$$

B. OFDM RECEIVER STRUCTURE

The receiver implements inverse operations of the transmitter. Received signal is passed through a receive filter at pass band and an Analog-to-Digital converter operating at a frequency of N/T. After these down converting and sampling operations, cyclic prefix is removed from the signal and a DFT operation is performed on the resultant complex points in order to demodulate the subcarriers. Subcarrier decoder converts obtained complex points to the corresponding bit stream.

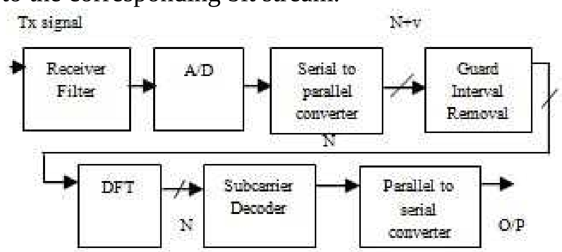

Fig. 2 Block Diagram of an OFDM Receiver

The Peak to Average Power Ratio (PAPR) is still one of the major drawbacks in the transmitted OFDM signal [4]. For zero distortion of the OFDM signal, the RF High Power Amplifier (HPA) must not only operate in its linear region but also with sufficient back-off. In digital transmission when the waveform is represented as signal samples, the PAPR is defined as

$$PAPR = \frac{\max(|S[n]|^2)}{E\{|S[n]|^2\}} \qquad (6)$$

Where S|n| represents the signal samples, max $(|S|n||^2)$ denotes the maximum instantaneous power and $E\{|S|n||^2\}$ is the average power of the signal.

Papr Reduction Using Radix-2 Decimation-In-Frequency (DIF) FFT

The proposed Radix-2 DIF FFT algorithm provides performance improvement in PAPR than standard OFDM system. In proposed scheme N/2 FFT is taken first at output of serial to parallel data convertor block. Then IFFT is taken and Parallel to serial conversion is performed. Let X_r is DFT of sequence x_l given as

$$X_r = \sum_{l=0}^{N-1} x_l w^{rl}, \; r = 0,1,\ldots,N-1 \qquad (7)$$

The radix-2 DIF FFT algorithm is obtained by decimating the output frequency series into an even-indexed set $\{X_{2k} \,|k = 0, \ldots , N/2 - 1\}$ and an odd-indexed set $\{X_{2k+1}|k = 0, \ldots , N/2 - 1\}$. The block diagram of proposed scheme is shown in figure3.

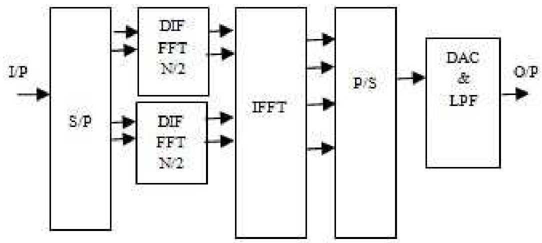

Fig. 3 Proposed scheme Block Diagram

To define the two half-size sub problems, equation (7) is rewritten as

$$X_r=\sum_{l=0}^{\frac{N}{2}-1} x_l w_N^{rl}+\sum_{l=\frac{N}{2}}^{N-1} x_l w_N^{rl} = \sum_{l=0}^{\frac{N}{2}-1}\left(x_l + x_{l+\frac{N}{2}} w_N^{r\frac{N}{2}}\right) w_N^{rl},\ r = 0,1,\ldots\ldots,N\text{-}1 \quad (8)$$

Defining $Y_k = X_{2k}$ and $y_l = x_l + x_{l+N2}$ yields the half-size sub problem

$$Y_k=\sum_{l=0}^{\frac{N}{2}-1} y_l w_{\frac{N}{2}}^{kl},\ k = 0,1,\ldots,N/2-1 \quad (9)$$

Defining $Z_k = X_{2k+1}$ and $X_l= (x_l - x_{l+\frac{N}{2}}) w_N^{l}$ yields the second half-size problem

$$Z_k=\sum_{l=0}^{\frac{N}{2}-1} x_l w_{\frac{N}{2}}^{kl},\ k = 0,1,\ldots,N/2-1 \quad (10)$$

Note that because $X_{2k} = Y_k$ in (9) and $X_{2k+1} = Z_k$ in (10), no more computation is needed to obtain the solution for the original problems after the two sub problems are solved. Therefore, in the implementation of the DIF FFT, the bulk of the work is done during the subdivision step, i.e., the set-up of appropriate sub problems, and there is no combination step. The computation of y_l and z_l in the subdivision step as defined above is referred to as the Gentleman-Sande butterfly in the literature, and is depicted by the annotated butterfly symbol in Figure4.

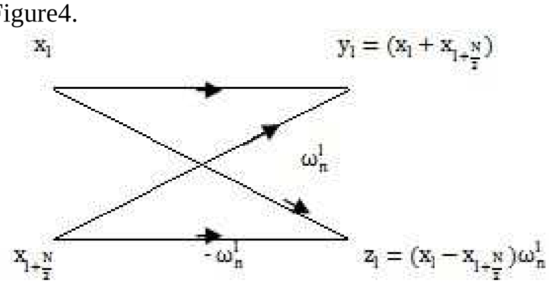

Fig. 4 The Gentleman-Sande butterfly

Simulation Results

Fig. 5 & 6 shows the CCDF of PAPR for standard OFDM and Radix-2 DIF FFT OFDM (Proposed Scheme). The parameters used for simulation as below.

Table I
Parameters used for simulation results

Modulation format	QPSK
Number of total subcarriers	512
Data block size	128
System bandwidth	5e6

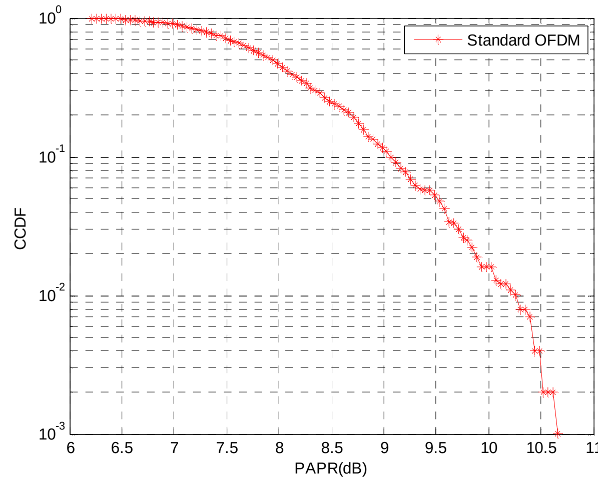

Fig. 5 Standard OFDM simulation result

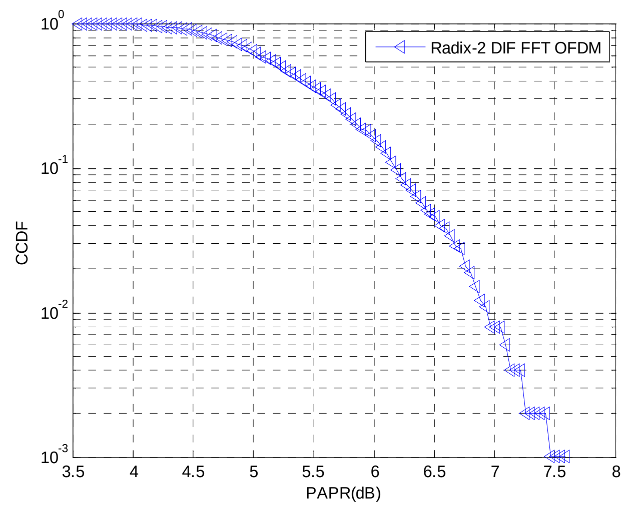

Fig. 6 Radix-2 Decimation in Frequency FFT OFDM simulation result

Table II
PAPR Standard OFDM Vs Radix-2 DIF FFT OFDM

CCDF	Standard OFDM	Radix-2 DIF FFT OFDM
10^{-2}	10.3 dB	7dB
10^{-1}	9 dB	6.2 dB

It can be seen clearly from figure5 & 6, PAPR power is reduced 3.3 dB using Radix-2 Decimation in

Frequency FFT OFDM technique at 10^{-2} CCDF and 2.8 db at 10^{-1} than standard OFDM.

Conclusion

OFDM is a promising technique for wireless communication systems although it has some drawbacks which are given below:

- High PAPR
- Frequency offset

High PAPR is one of the major problems of OFDM system. There are several techniques to reduce the PAPR in OFDM transmission system. All PAPR reduction techniques have some advantages and disadvantages. In the proposed scheme, we have used signal processing technique to reduce PAPR. The proposed radix 2 FFT algorithm provides 3dB performance improvement than standard OFDM system as shown by simulated results carried out in MATLAB.

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