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PERFORMANCE IMPROVEMENT OF OFDM SYSTEM BY PEAK TO AVERAGE POWER REDUCTION THROUGH PULSE SHAPING TECHNIQUE

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Abstract
OFDM is a form of multicarrier modulation technique with high spectral efficiency, robustness to channel fading, immunity to impulse interference, uniform average spectral density capacity of handling very strong echoes and non-linear distortion. Despite of its many advantages, one major disadvantage of OFDM is that the time domain OFDM signal which is a sum of several sinusoids leads to high peak to average power ratio (PAPR). The peak to average power ratio of the time domain envelope is an important parameter at the physical layer of the communication system using OFDM signaling. The signals must maintain a specified average energy level in the channel to obtain the desired Bit-error-rate. Pulse shaping techniques are very effective and mitigate problems associated with PAPR. In this paper conventional pulse shapes like Raised Cosine (RC), and sinc Power (SP) pulses are modified as Modified Raised Cosine Pulse (MRC) and Improved sinc Power pulse (ISP) introducing design parameter 'd' and amplitude parameter 'a' etc . The proposed method has fast decaying rate by decreasing the lobes of sinc function and its implementation complexity is also less. In this paper OFDM system performance measures like Complementary Cumulative Distribution Function (CCDF) of PAPR and bit error rate (BER) are analyzed through MATLAB simulation which proves the efficacy of the proposed pulse shaping scheme. It was observed from the performance curves using ISP pulse shaping filter at the OFDM transmitter's end outperforms others.

Keywords:
OFDM, Peak-to-Average Power Ratio (PAPR), Pulse Shaping, CCDF, Bit Error Rate

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has been considered as a promising candidate to achieve high rate data transmission in a mobile environment [1] [2]. Recently, OFDM systems are being applied for fixed and mobile transmission. Some examples of existing systems where OFDM is used are digital audio and video broadcasting, and Asymmetric Digital Subscriber Line (ADSL) modems. Moreover, the new generation of Wireless Local Area Networks systems (WLANs) is based on similar WLAN standards known as: IEEE 802.11a (US), and HiperLAN/2 (Europe) [3]. These systems support a physical layer transmission rate up to 54 Mbps and use OFDM for the physical layer implementation [3][4]. Additionally, OFDM is being considered for future broadband applications such as Wireless Asynchronous Transfer Mode ATM and fourth generation transmission techniques.

The major drawback of the OFDM scheme is the large signal Peak to Average Power Ratio (PAPR) due to the large number of sub-carriers, with random phase and amplitude that are summed in the modulator. These causes in the presence of a nonlinear High Power Amplifier (HPA) signal distortion that result in out-of band radiation and inter-modulation noise.

Conventional solution to reduce PAPR is to back off the operating point of the nonlinear amplifier. But both solutions result in a significant loss of power efficiency. Nowadays several other techniques have been proposed, such as clipping with filtering, block coding, and selected mapping, Partial - Transmit Sequence and etc. However most of these methods cause signal distortion that results in BER degradation or odd redundancy that results in increase of transmission bandwidth.

So the reduction achieved by these techniques is relative. Other possible alterative solution is to try to exploit the parameters of the OFDM signal by creating some correlation. Exploiting the subcarrier waveforms of the OFDM signal appears as an attractive solution for reducing the PAPR of OFDM signals [5]. This approach has the potential of reducing the PAPR of the OFDM signal without affecting the bandwidth efficiency of the system.

In this paper a novel method based on modified pulse shaping technique is proposed to reduce the PAPR of OFDM signals with low complexity. It has been shown in literature [6] that the PAPR of OFDM signals can be reduced if the subcarrier waveforms have different shapes. We propose that using a proper selection of all types of pulses to shape the subcarrier waveforms can achieve significant improvement in PAPR reduction.

This paper is organized as follow: In Section II, the OFDM system model is introduced. Definition of the PAPR of OFDM signals and the approach of pulse shaping in reducing the PAPR are described in Section III. A new set of subcarrier waveforms introducing pulse shaping filters for reducing PAPR of OFDM signals is proposed in Section IV. Some conclusions and discussions are drawn in Section V.

2. SYSTEM MODEL

The Fig.1 illustrates the transmitter block diagram of a N sub-carrier OFDM system using pulse shaping. Here the incoming data is first modulated in baseband using a bandwidth efficient modulation (QPSK modulation). The baseband-modulated stream, with data rate $1/T_s$ is then split into N parallel streams. Each stream is shaped by a time waveform (pulse shaping waveform) and transmitted over a given subcarrier. Thus the OFDM transmitted signal can be expressed as

$$x(t)=\sum_{k=0}^{N-1} X_n(k)p_k(t)e^{j2\pi k\frac{t}{T}}, \quad nT\le t\le (n+1)T \tag{1}$$

where $X_n(k)$ the modulated data symbol of sub-carrier is k, T is the duration of the OFDM block. The waveform $p_k(t)$ is a pulse shape, of duration T, used at subcarrier k and having a bandwidth less or equal to the bandwidth of the OFDM signal $x(t)$. The OFDM band-pass signal is related to its equivalent low-pass by the following expression:

$$s(t) = \Re\{x(t)\ e^{j2\pi f_c t}\} \tag{2}$$

where f_c is the carrier frequency. The total bandwidth of the OFDM band-pass signal can be approximated as follows:

$$B_s \approx \frac{1}{T_s} + \frac{\beta}{T_s}$$

where $0 \le \beta < 1$ is a coefficient related to the number of subcarrier and the transmit filter. And T_s is the symbol duration of the baseband modulated signal.

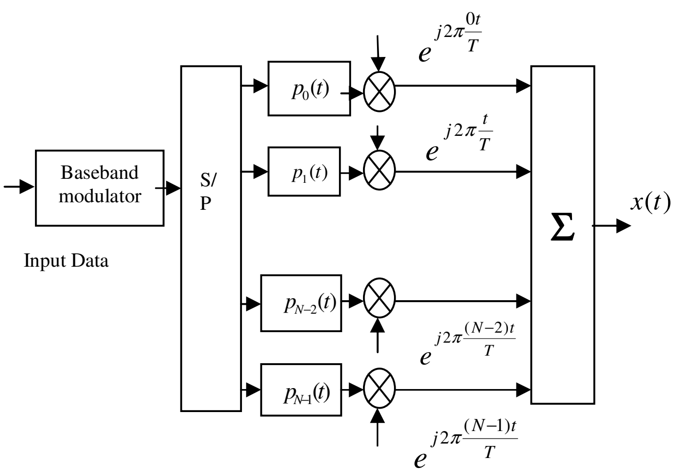

Fig.1. OFDM Transmitter Model Using Pulse Shaping

3. PEAK-TO-AVERAGE POWER RATIO OF OFDM SIGNALS

The peak-to-average power ratio of the OFDM transmitted signal of eq. (1) can be defined as follows:

$$PAPR = \frac{\max|x(t)|^2}{E\{|x(t)|^2\}} \tag{3}$$

Assuming uncorrelated symbols within each OFDM block, the maximum PAPR is obtained as

$$PAPR_{\max} = \frac{1}{N} \max_{0 \le t \le T} \left(\sum_{m=0}^{N-1} |p_k(t)| \right)^2 \tag{4}$$

which is a function of the number of subcarriers N and the pulse shape used at each subcarrier. With large number of subcarriers, the maximum of the PAPR occurs with very low probability. A better measure of the PAPR of communication signals is to use the complementary cumulative distribution function (CCDF) defined as

$$P_{PAPR} = \Pr(PAPR \ge PAPR_0)$$

where $PAPR_0$ is the PAPR threshold.

4. EFFECT OF PULSE SHAPE IN PAPR REDUCTION

A possible solution to reduce the PAPR of OFDM signals is to create some correlation between the different OFDM samples of the same block. By making the cross-correlation close one, a multicarrier signal with very low PAPR is obtained. The cross-correlation function of the OFDM signal is obtained as:

$$R_s(t_1, t_2) = \sum_{n=0}^{N-1} \sum_{k=0}^{N-1} \overline{s_{n,l} s_{k,l}^*}\, p_n(t_1)\, p_k^*(t_2)\, e^{j2\pi(nt_1 - kt_2)/T} \tag{5}$$

The cross correlation function is a function of the signal modulated symbol and the subcarrier waveforms. Hence, increasing the correlation between the OFDM signal samples of the same block can be increased through these two parameters. As a result, the PAPR of OFDM signal can be reduced. The use of time waveforms of the different subcarriers is suggested as a way of reducing the PAPR of the OFDM signal without affecting the bandwidth efficiency of the system. A set of time waveforms that reduces the PAPR of OFDM signals was proposed in [9]. However, the reduction obtained was not considerable. The reason for the limited improvement in PAPR is due to the fact that the set proposed in [9] is formed of narrowband pulses. Better reduction in PAPR of OFDM signals may be achieved by using broadband pulse shapes.

A time waveform $p(t)$ with constant energy equals to T and having the following properties is considered here.

$$\begin{cases} p(t) = 0, & |t - T/2| > T/2 \\ P(f) \approx 0, & |f - 1/(2T_s)| > \dfrac{1}{2T_s} + \dfrac{\beta}{2T_s} \end{cases} \tag{6}$$

As the waveform $p(t)$ is time limited, it can be approximated by the Fourier series representation within the interval of definition T, i.e.,

$$p(t) \approx \sum_{l=-L}^{N+L-1} C(l) e^{j2\pi\frac{l}{T}t}, \qquad 0 \le t < T \tag{7}$$

$$C(l) = \frac{1}{T}\int_0^T p(t) e^{-j2\pi\frac{l}{T}t} dt = \frac{1}{T} p\left(\frac{k}{T}\right) \tag{8}$$

where

where $L = \lfloor N\beta/2 \rfloor$ and $C(l)$ is the Fourier series coefficient of $p(t)$.

Using the waveform $p(t)$, the pulse shape of subcarrier k is defined as follows

$$p_k(t) = \sum_{l=-L}^{N+L-1} C(l) e^{-j2\pi\frac{kl}{N}} e^{j2\pi\frac{l-k}{T}t}, \qquad 0 \le t < T \tag{9}$$

$$p_k(t) e^{j2\pi\frac{k}{T}t} = p_i(t - \tau_{k-i}) e^{j2\pi\frac{i}{T}(t - \tau_{k-i})} \tag{10}$$

where, $\tau_{k-i} = [(k-i) \bmod N] T_s$.

It indicates that the subcarrier waveforms of the OFDM modulation, as defined above, are cyclic shifts of each other within the time interval $0 \le t < T$. With this property the peak amplitudes of the N subcarrier waveforms will not occur at the same time, and thus the peak power to average power ratio (PAPR) of the OFDM signal will be reduced. Hence the selection of pulse shaping function as discussed in the subsequent section is done maintaining the orthogonality property between the different subcarriers as given below.

$$\int_0^T p_k(t) p_l^*(t) e^{j2\pi \frac{k-l}{T} t} dt = \begin{cases} T, & l = k \\ 0, & l \ne k \end{cases}. \tag{11}$$

5. EFFECT OF PULSE SHAPE IN PAPR REDUCTION

Two new pulse shaping functions, denoted as Improved Sinc power pulse (ISP) suggested in [8]. And Modified Raised Cosine (MRC) suggested in [9] is employed to reduce PAPR and ICI power functions of N-subcarrier OFDM system. Researchers have worked to improve the conventional pulse shaping filters (rectangular (REC), raised cosine (RC), and Sinc power pulse (SP)) [10] over the years. The Improve Sinc Power (ISP) Pulse [11] [12]is implemented considering a design parameter 'a' which adjusts the amplitude of the conventional sinc pulse and has a fast decaying rate decreasing the lobes of Sinc function.

Similarly certain modifications are incorporated in the raised cosine function to develop MRC pulse shape by introducing a new design parameter called the shaping parameter d which shapes the impulse response and minimizes the PAPR of the transmitted signal.

A. Improved sinc power pulse

$$P_{ISP}(f) = \exp\{-a(fT)^2\} \operatorname{sinc}^m(fT) \tag{12}$$

Where '*a*' is a design parameter to adjust the amplitude and *m* is the degree of the sinc function.

B. Modified Raised Cosine pulse

$$P(f) = \begin{cases} T & 0 \le |f| \le \frac{1-\alpha}{2T} \\ \frac{T}{2}\left\{1 + \cos\left[\frac{\pi T}{\alpha}\left(|f| - \frac{1-\alpha}{2T}\right)\right]\right\} & \frac{1-\alpha}{2T} \le |f| \le \frac{1+\alpha}{2T} \\ 0 & |f| > \frac{1+\alpha}{2T} \end{cases} \tag{13}$$

where α is the roll-off factor that determines the filter bandwidth $B = (1+\alpha)/2T$ [13][14].Researchers have studied to improve the conventional raised cosine filter by incorporating new parameters. The conventional raised cosine solution, given in Eq. (13), is obtained by fitting a (raised) half-cycle of cosine, in the transition region, $\frac{1-\alpha}{2T} \le |f| \le \frac{1+\alpha}{2T}$. Here modification is based on simply allowing any multiple or fraction of cosine cycles to be fitted in the transition region; this is done by introducing a multiplicative factor d that scales the period (in frequency domain) of the raised cosine function. It is found that d is inversely related to the length of cosine cycles fitted in the transition region, measured relative to one half cycles.

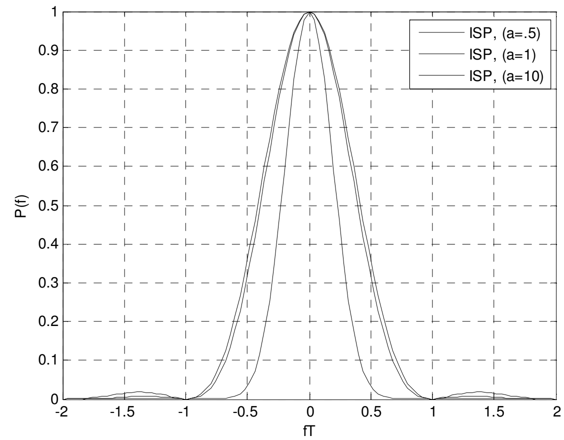

Fig.2(a). Spectral Comparison of ISP Pulse Shapes for m=2& varying the design parameter 'a'

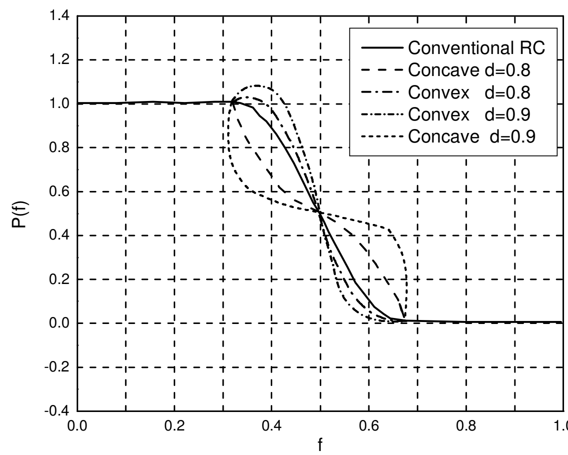

Fig .2(b). Modified Raised Cosine Spectra (in frequency domain) for α =0.35

Fig. 2 (a) shows the spectral comparison of ISP Pulse Shapes for m=2 & varying design parameter 'a'. As shown in Fig.2 (a), increasing a from 0.5 to 10, the amplitude in the frequency space decreases. For very large values of *a* (*a* =10), ISP pulse shape converges to a narrow pulse shape.

The Fig.2 (b) shows the range of spectral shaping possible by varying *d*. There can be two types of modified solutions, known as "convex" and "concave". The names denote the curvature of the response in the first half portion of the transition region.

6. SIMULATION RESULT

The Fig.3 illustrates the complementary cumulative distribution function (CCDF) of the PAPR for a 64 subcarrier OFDM signals using different pulse shapes. It is observed that the pulse shaping technique is beneficial providing considerable gain in PAPR reduction compared to that of conventional

OFDM. This is because the improved sinc pulse has the smallest side-lobe and peak amplitudes of subcarrier waveforms do not occur at the same time instant. It is found that ISP pulse shape outperforms to all other pulse shaping functions in terms of PAPR reduction.

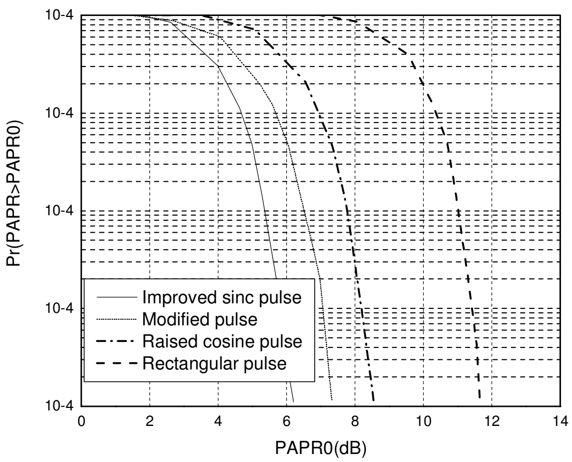

Fig.3. CCDF of the PAPR Using Different Pulse Shape

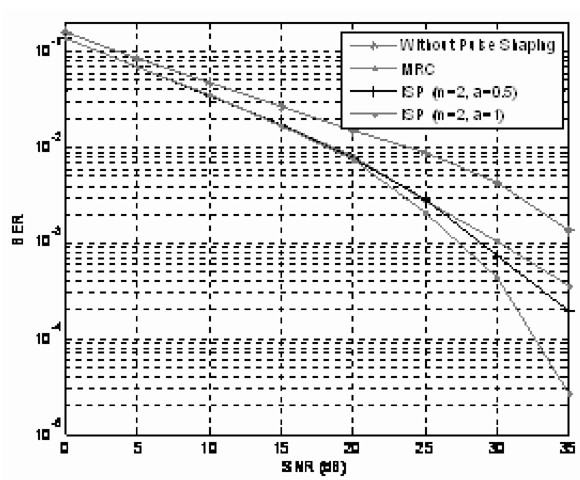

Fig.4. BER performance of QPSK-OFDM system for without and with Pulse Shaping ΔfT=0.25

Fig.4 shows that BER performance improves using pulse shaping. At a BER level of 10^{-3}, SNR gains of around 8dB and 6dB are observed for OFDM system using ISP (*m*=2, a=1) and ISP (*m*=2, a=0.5) respectively. SNR improvement is also observed using MRC pulse at a fixed BER level. Hence with the proposed pulse shaping approach, effects of both the drawbacks of OFDM system, i.e., PAPR is reduced. So performance enhancement of the OFDM system is observed.

7. CONCLUSION

In this paper, a modified pulse shaping technique is proposed to reduce the PAPR in OFDM system. The method is based on proper selection of the design parameters of modified pulses for shaping the different subcarriers of OFDM scheme. Two improved modified pulses and usual raised cosine pulse are used to design the set of shaping pulses for PAPR reduction in OFDM system. It is observed by MATLAB simulation that the proposed method can achieve significant improvement in PAPR reduction in OFDM system. The Improve sinc Power (ISP) Pulse is implemented considering a design parameter 'a' which adjusts the amplitude of the conventional sinc pulse and has a fast decaying rate decreasing the lobes of sinc function. The optimized pulse shapes can achieve better PAPR reduction compared to conventional pulse shapes. The proposed technique is very effective and flexible for any number of carriers. Thus pulse shaping technique can be used not only to shape the spectrum of the transmitted signal but also to reduce high PAPR and simultaneously improve BER performance of the system.

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