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Research Article

ICI Alleviation in OFDM System Utilizing Scale Alpha Pulse Shaping

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Abstract: In this study, a new pulse shaping method namely scale alpha is proposed for mitigating Inter-Carrier Interference (ICI) effect in Orthogonal Frequency-Division Multiplexing (OFDM) system. The suggested pulse shape is designed and simulated using MATLAB software. Results show that the new pulse shape has lower ICI power and better impulse response performance than Franks, raised cosine and double-jump pulses.

Keywords: ICI, nyquist pulse, OFDM, pulse shapes, scale alpha

INTRODUCTION

Orthogonal Frequency-Division Multiplexing (OFDM) is attractive because it can meet the demands of wireless communication technologies for fourth-Generation (4G). Guard intervals are always inserted to avoid multipath fading effects in OFDM communication. Frequency offset leads to Inter-Carrier Interference (ICI) and hence performance degradation. OFDM has been used in various wireless systems due to its strong robustness against multipath effect (Obara *et al*., 2013). It has been proven that high data speed transmission in mobile environment is achieved by OFDM system due to its ability to decompose a wideband frequency selective fading channel into several parallel narrow band flat fading channels (Assimonis *et al*., 2010; Palaivelan *et al*., 2012). Multi-path delay spread tolerance, immunity to frequency selective fading channels, high spectral efficiency (by allowing the sub carriers to overlap in the frequency domain) and efficient modulation and demodulation techniques and robust to impulse noise are the leading advantages of OFDM system. OFDM technique has potential of enhancing the data rate in band limited channel. However, ICI and high Peak to Average Power Ratio (PAPR) are main drawbacks of OFDM system. The performance of OFDM system can be made better by using efficient pulse shaping techniques. In Lin *et al*. (2008), a pulse shaping function has been suggested to reduce the sensitivity of OFDM system to frequency offset which leads to ICI. It has been shown that with various pulse shapes, the performance of OFDM system is improved compared to without pulse shaping functions (Gandhi *et al*., 2013). In this study, a new scale alpha pulse shaping is suggested to alleviate ICI influence in OFDM system.

METHODOLOGY

System model: Figure 1 illustrates the typical block diagram of OFDM communication system. In this system, Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (16-QAM) and 64-QAM constellation maybe used to map binary information. The high-speed serial data stream is split up into a set of low-speed sub streams and modulated onto the orthogonal carriers through Inverse Fast Fourier Transform (IFFT). Signal x (t) which is represented in Eq. (1) is transmitted through the channel with various pulse shaping functions. The complex envelope of one Radio Frequency (RF) N-subcarrier OFDM symbol with pulse-shaping is expressed as (Richard and Prasad, 2002):

$$x(t) = \exp(j2\pi f_c t) \sum_{k=0}^{N-1} a_k \, p(t) \exp(j2\pi f_k t) \qquad (1)$$

where,

f_c = The carrier frequency
f_k = The kth subcarrier frequency
N = The number of subcarriers
$p(t)$ = The pulse shaping function
$a_k (k = 0,1,\ldots,N-1)$ = The data symbol transmitted on the kth subcarrier

The data symbols are assumed to have zero mean and normalized average energy. They are also assumed to be uncorrelated and satisfy (Obara *et al*., 2013):

$$E[a_k a_m^*] = \begin{cases} 1 & k=m \\ 0 & k\neq m \end{cases} \qquad (2)$$

where, a_m^* is the complex conjugate of a_m. To ensure the subcarrier orthogonality which is very important for OFDM systems, the equation below has to be satisfied:

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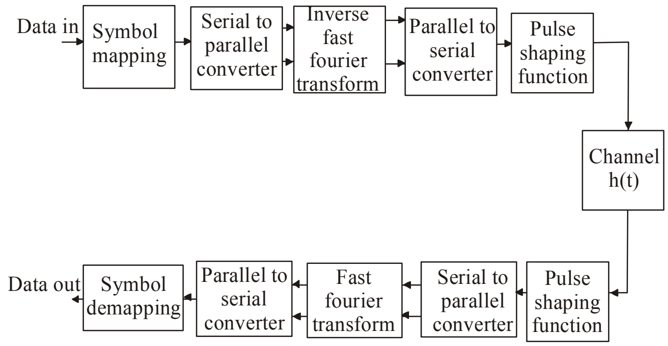

Fig. 1: Simulation block diagram of OFDM system

$$f_k\text{-}f_m = \frac{k-m}{T} \tag{3}$$

where, $\frac{1}{T}$ is the minimum subcarrier frequency spacing required to satisfy orthogonality between subcarriers. Hence, at the receiver the signal is expressed as:

$$r'(t) = x(t) \otimes h(t) + n(t) \tag{4}$$

where,

$n(t)$ = The additive white Gaussian noise process with zero mean and variance $\frac{N_0}{2}$ per dimension

$\otimes$ = Convolution

$h(t)$ = The channel impulse response

In this study, we assume that the channel is ideal, i.e., $h(t) = \partial(t)$ in order to investigate the effect of the frequency offset only on the ICI performance, where $\partial(t)$ is the same with $h(t)$ to shows the ideality. Doppler spread introduces a frequency offset $\Delta f \geq 0$.Then the signal received after multiplication by the carrier frequency $(f_c + \Delta f)$ is given by:

$$r(t) = \exp(j2\pi\Delta f t)\sum_{k=0}^{N-1} a_k\, p(t)\exp(j2\pi f_k t) + n(t)\exp[j2\pi(-f_c + \Delta f)t] \tag{5}$$

where,

$n(t)$ = The additive white Gaussian noise

Finally, the output of the mth subchannel correlation demodulator gives the decision variable for the transmitted symbol:

$$\hat{a}_m = a_m P(-\Delta f) + \sum_{\substack{k=0\\k\neq m}}^{N-1} a_k p\left(\frac{m-k}{T} - \Delta f\right) + n(m) \tag{6}$$

The first term contains the desired signal component, whereas the second term is the ICI. The ICI power depends on the number of subcarriers and the spectral magnitudes of the pulse shaping functions. The power of the desired signal can be calculated as:

$$\sigma(m)^2 = E[a_m P(-\Delta f) a_m^* P(-\Delta f)^*] = E[a_m a_m^*]|P(\Delta f)|^2 = |P(\Delta f)|^2 \tag{7}$$

Then, the power of the ICI can be stated as:

$$\sigma(ici)^2 = \sum_{k=0}^{N-1}\sum_{n=0}^{N-1}[a_n a_k^*][P\left(\frac{k-m}{T} + \Delta f\right) \times P\left(\frac{k-m}{T} + \Delta f\right)] \tag{8}$$

The average ICI power across different sequences can be calculated as:

$$\sigma(ici)^2 = E[\sigma[ici))^2] = \sum_{\substack{k=0\\k\neq m}}^{N-1} \left|P(\frac{k-m}{T} + \Delta f)\right|^2 \tag{9}$$

As seen in Eq. (9) the average ICI power depends on the number of the subcarriers and $P(f)$ at frequencies $\left(\left(k - \frac{m}{T}\right) + \Delta f\right), k \neq m.$ By using Eq. (7) and (9), the Signal-to-Interference Ratio (SIR) can be defined as:

$$\text{SIR} = \frac{|P(\Delta f)|^2}{\sum_{\substack{k=0\\k\neq m}}^{N-1} \left|P(\frac{k-m}{T} + \Delta f)\right|^2} \tag{10}$$

Pulse shaping functions: Each carrier in the OFDM spectrum is represented by main lobe with a number of side lobes having lower amplitudes. Since peak power is associated with main lobe and ICI power is associated with side lobes, so the motive of pulse shaping function is to increase the width of main lobe and reduce the amplitude of side lobes. Proper pulse shaping techniques makes a digital communication system possible to transmit data within a limited BW with minimum ISI (Pal, 2012). OFDM remains a chosen modulation scheme for upcoming broadband radio area systems because of its inherent flexibility in power loading across the subcarriers and concerning adaptive modulation (Gayathri *et al.*, 2013).

Here, we consider double-jump pulse $p_{dj}(t)$, raised cosine pulse $p_{rc}(t)$, Franks pulse, $p_f(t)$ and scale alpha pulse, p $(t)_{s\text{-}\alpha}$.$P_{dj}(f)$, $P_{rc}(f)$ and, $P_f(f)$

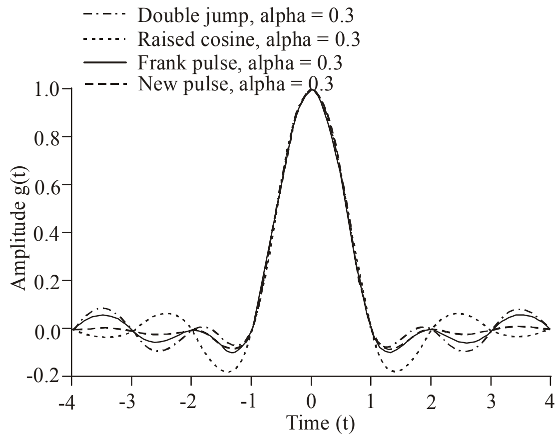

Fig. 2: Impulse response in time domain when α = 0.3

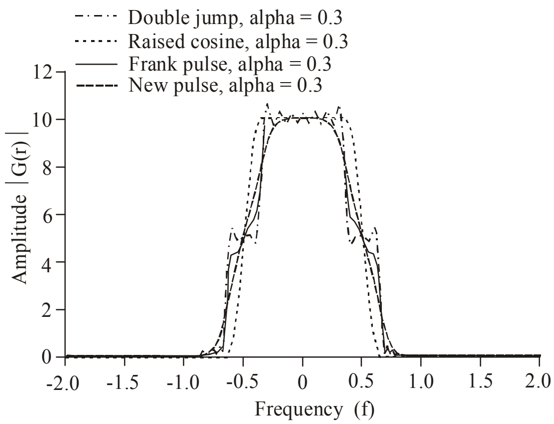

Fig. 3: Impulse response in frequency domain when α = 0.3

are the Fourier transform of $p_{dj}(t)$, $p_{rc}(t)$ and $p_f(t)$, respectively. They are given as:

$$p_{dj}\ (f) = \text{sinc}\ (fT_u)\cos\ (\pi\alpha f T_u) \tag{11}$$

where,

$$\text{Sinc}\ (x) = \begin{cases} 1, & x=0 \\ \frac{\sin\ (\pi x)}{\pi x}, & x\neq 0 \end{cases}$$

$$p_{rc}\ (f) = \text{sinc}\ (fT_u)\frac{\cos\ (\pi\alpha t T_u)}{1-(2\alpha t T_u)^2} \tag{12}$$

$$p_f\ (f) = \text{sinc}\ (fT_u)[(1-\alpha)\cos\ (\pi\alpha f T_u + \alpha sinc(\alpha f T_u)] \tag{13}$$

$$p\ (t)_{s\text{-}\alpha} = \{(1-(t/2s)^2)\exp\ (-(t/2s)^2)/2\} \times \{\frac{Sin(\pi t)Cos(\alpha\pi t)}{\pi t - 2\pi\alpha t^2}\} \tag{14}$$

where, α is the roll of factor ($0 \leq \alpha \geq 1$) and$s$ is the number of scale.

RESULTS AND DISCUSSION

To observe the effect of various of α, simulations are performed for $\alpha = 0.3$ and 1. Figure 2 and 3 show

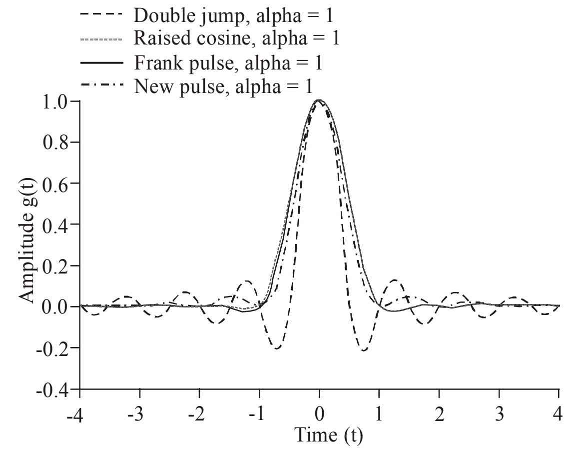

Fig. 4: Impulse response in time domain when α = 1

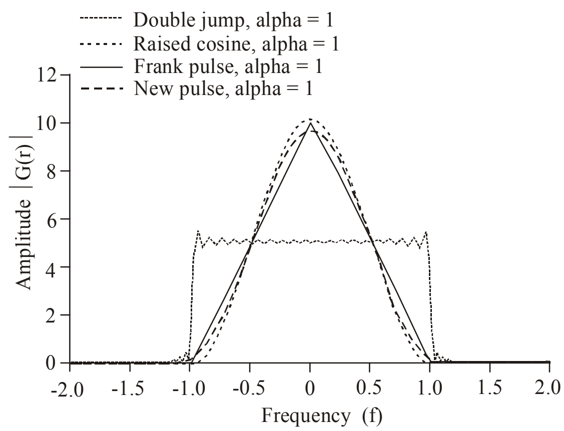

Fig. 5: Impulse response in frequency domain when α = 1

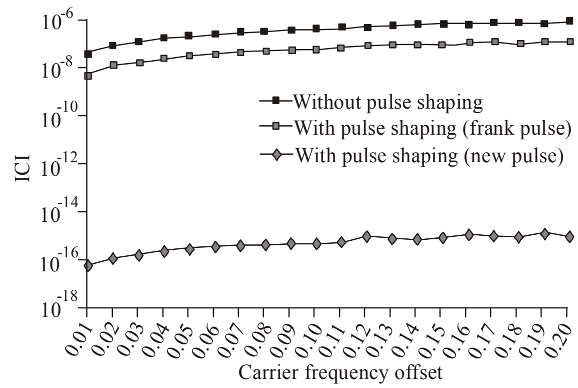

Fig. 6: Comparison for with and without pulse shaping for new and Franks pulses when α = 0.3

the impulse response for different pulse shape at $\alpha = 0.3$ in time and frequency domains, respectively. It can be clearly seen that the new scale alpha pulse shape have lesser side lobes amplitude compared to other pulses. So, our proposed scale alpha pulse shape has a reduced ICI power in comparison with other pulse shape as the side lobes contains the ICI power (Gandhi *et al*., 2013; Yadav *et al*., 2014). Furthermore, Fig. 4 and 5 depict the impulse responses at $\alpha = 1$. It is observed that when α increased from 0.3 to 1, the side lobes has lower amplitudes for all pulses, which results in better performance in terms of ICI reduction.

Figure 6 shows the comparison of without and with pulse shaping for Franks and new pulses. For Franks pulse with pulse shaping, when the x-axis is 0.01, the value of ICI in y-axis is 5.824×10^{-9}. While the new pulse crosses lower ICI value of 5.849×10^{-17} at the same carrier frequency offset value. Whereas, for without pulse shaping, the ICI value is 3.826×10^{-8} when carrier frequency offset is 0.01. This situation demonstrates that the ICI power is mitigated by 7.18% utilizing the newly proposed pulse compared to Franks pulse.

CONCLUSION

In this study, simulation results are presented to compare different shaping methods in OFDM system. It can be seen that our suggested scale alpha pulse has lesser side lobes amplitude compared to Franks, raised cosine and double-jump pulses. Moreover, the new pulse performs better by achieving 7.18% reduction of ICI power in comparison with Franks pulse when $\alpha = 0.3$.

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