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A Comparative Study of Nyquist Pulse-Shaping Impact on Performance of Coded OFDM Systems with Carrier Frequency Offset

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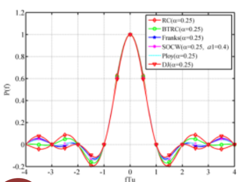
Graphical abstract



Abstract

Nyquist Pulse-shaping is one of the methods used to mitigate the effects of frequency offset in OFDM system which result in intercarrier interference (ICI). In this paper, the performance of coded OFDM (COFDM) with various Nyquist pulse shaping over AWGN channel with carrier frequency offset (CFO) are investigated. It is observed from simulation results that the Franks pulse outperforms all Nyquist pulses considered here in term of BER performance. Numerical results for ICI power reduction show that Franks and DJ pulses are quite similar, and outperform other pulses considered in this paper.

Keywords: OFDM; forward error correction; pulse-shaping; frequency offset; ICI

1.0 INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a strong candidate for future wireless communication due to its high spectral efficiency, and its robustness against multi-path delay. OFDM has been used in many standards such as digital video/audio broadcast (DVB/DAB), IEEE 802.11a, and 802.16, etc. [1]. However, a major drawback of OFDM is its sensitivity to CFO. CFO may occur due to frequency difference between local oscillators in the transmitter and receiver and Doppler shift. The CFO destroys the orthogonality among subcarriers and causes ICI, which significantly degrade the performance of OFDM [2-4].

Different approaches have been developed to mitigate ICI in OFDM systems including, ICI self-cancellation scheme [5, 6], frequency domain equalization [7, 8], tim-domain windowing at the receiver [9, 10], and pulse-shaping [11, 12].

Many forward error codes, including convolutional codes, Reed-Solomon codes, and Turbo codes have been used in OFDM systems to improve performance. To obtain high coding gains with moderate decoding complexity concatenated codes is used. Classically, concatenated code are used in coded OFDM (COFDM) systems in which and the outer code is Reed-Solomon (RS) and the inner code is a convolutional code (CC) with Viterbi decoding [13].

In this paper we investigate the performance of COFDM with various Nyquist pulse-shaping over AWGN channel with CFO, which is not available in literature studies. Various Nyquist pulse-shaping, including Raised cosine (RC) pulse, 'Better than' raised-cosine (BTRC) pulse, Franks Pulse, Second order continuous window (SOCW) pulse, Polynomial pulse, and Double jump (DJ) are considered for comparison.
The rest of this paper is structured as follows. In Section 2.0 a description of COFDM System model is presented. Pulse shaping functions are given in Section 3.0. In Section 4.0 ICI analysis and numerical results are given. Simulation results are discussed in Section 5.0. Finally, conclusions are drawn in Section 6.0.

2.0 SYSTEM MODEL

Figure 1 shows a block diagram of OFDM Transreceiver with channel coding and decoding. In this paper we consider RS encoder (255, 239, 8), with CC with 1/2 rated code, constraint length $k = 7$, and with generator polynomials $g_1=171_8$ and $g_2=133_8$, followed by block interleaving of 12 depth [13]. The encoded data is mapped by one of following digital modulation techniques binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), and 16 quadrature amplitude modulation.

We consider in our model an AWGN channel with CFO, Δf ($\Delta f \geq 0$). The complex envelope of the transmitted OFDM symbol with pulse-shaping is expressed as

$$x(t) = e^{j2\pi f_c t} \sum_{k=0}^{N-1} D_k p(t) e^{j2\pi f_k t} \tag{1}$$

where f_c is the carrier frequency, D_k is a complex data symbol that modulating the kth subcarrier, $p(t)$ is the pulse-shaping function, and f_k is the kth subcarrier frequency.

One also has

$$f_k - f_m = \frac{k-m}{T_u}, k, m = 0,1, \ldots N-1 \qquad (2)$$

to ensure orthogonality between subcarriers; that is

$$\int_{-\infty}^{+\infty} p(t) e^{j2\pi(f_k - f_m)t} dt = \begin{cases} 1, & k = m \\ 0, & k \neq m \end{cases} \qquad (3)$$

where $1/T_u$ is the minimum subcarrier spacing for orthogonality.

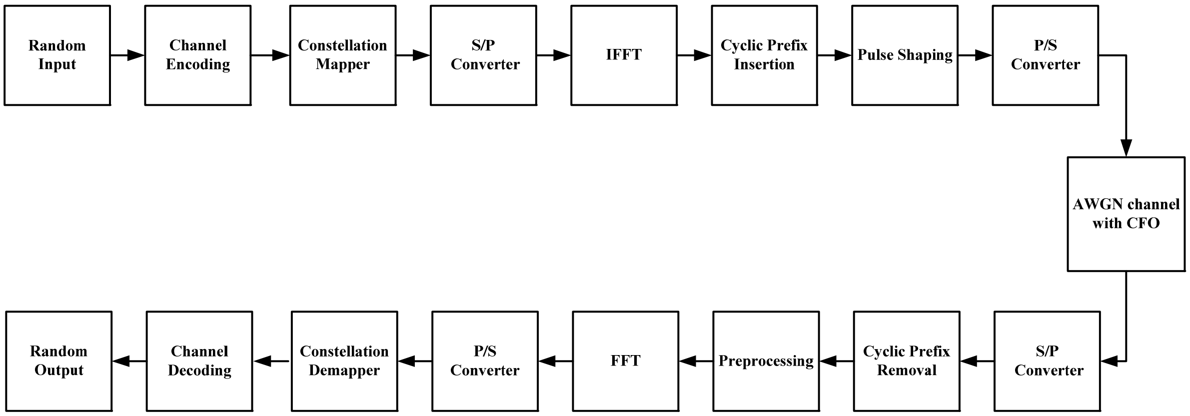


Figure 1 Simulated model of COFDM with pulse shaping

3.0 PULSE SHAPING FUNCTIONS

For performance comparison of pulse shaping on COFDM, we consider six Nyquist pulses which are reported previously in this paper. In the time-domain let's denoted them as $p_{\mathrm{RC}}(t)$, $p_{\mathrm{BTRC}}(t)$, $p_{\mathrm{Franks}}(t)$, $p_{\mathrm{SOCW}}(t)$, $p_{\mathrm{Poly}}(t)$, and $p_{\mathrm{DJ}}(t)$, which are defined in Equations (4-9), respectively [14].

$$p_{\mathrm{RC}}(t) = \begin{cases} \frac{1}{T_u} & |t| \leq \frac{T_u(1-\alpha)}{2} \\ \frac{1}{2T_u}\left\{1 + \cos\left[\frac{\pi}{\alpha T_u}\left(|t| - \frac{T_u(1-\alpha)}{2}\right)\right]\right\}, & \frac{T_u(1-\alpha)}{2} \leq |t| \leq \frac{T_u(1+\alpha)}{2} \\ 0, & \text{otherwise} \end{cases} \qquad (4)$$

$$p_{\mathrm{BTRC}}(t) = \begin{cases} \frac{1}{T_u}, & |t| \leq \frac{T_u(1-\alpha)}{2} \\ \frac{1}{T_u}\exp\left(\frac{-2\ln 2}{\alpha T_u}\left[|t| - \frac{T_u(1-\alpha)}{2}\right]\right), & \frac{T_u(1-\alpha)}{2} \leq |t| < \frac{T_u}{2} \\ \frac{1}{T_u}\left\{1 - \exp\left(\frac{-2\ln 2}{\alpha T_u}\left[\frac{T_u(1+\alpha)}{2} - |t|\right]\right)\right\}, & \frac{T_u}{2} \leq |t| < \frac{T_u(1+\alpha)}{2} \\ 0, & \text{otherwise} \end{cases} \qquad (5)$$

$$p_{\mathrm{Franks}}(t) = \begin{cases} \frac{1}{T_u} & |t| \leq \frac{T_u(1-\alpha)}{2} \\ \frac{1}{T_u}\left(1 - \frac{|t|}{T_u}\right), & \frac{T_u(1-\alpha)}{2} \leq |t| < \frac{T_u(1+\alpha)}{2} \\ 0, & \text{otherwise} \end{cases} \qquad (6)$$

$$p_{\mathrm{SOCW}}(t) = \begin{cases} \frac{1}{T_u}, & |t| \leq \frac{T_u(1-\alpha)}{2} \\ \frac{1}{T_u}\left[1 - f\left(-\frac{2|t|}{\alpha T_u} + \frac{1}{\alpha}\right)\right], & \frac{T_u(1-\alpha)}{2} \leq |t| < \frac{T_u}{2} \\ \frac{1}{T_u} f\left(\frac{2|t|}{\alpha T_u} - \frac{1}{\alpha}\right), & \frac{T_u}{2} \leq |t| < \frac{T_u(1+\alpha)}{2} \\ 0, & \text{otherwis} \end{cases} \qquad (7)$$

where $f(t) = 0.5 + a_1 t - (0.5 + a_1)t^2$

$$p_{\mathrm{Poly}}(t) = \begin{cases} \frac{1}{T_u}, & |t| \leq \frac{T_u(1-\alpha)}{2} \\ \frac{1}{T_u} g\left[\frac{|t| - T_u(1-\alpha)/2}{\alpha T_u}\right], & \frac{T_u(1-\alpha)}{2} \leq |t| < \frac{T_u}{2} \\ \frac{1}{T_u}\left\{1 - g\left[\frac{T_u(1+\alpha)/2 - |t|}{\alpha T_u}\right]\right\}, & \frac{T_u}{2} \leq |t| < \frac{T_u(1+\alpha)}{2} \\ 0, & \text{otherwise} \end{cases} \qquad (8)$$

where $f(t) = 0.5 + a_1 t - (0.5 + a_1)t^2$

$$p_{\mathrm{DJ}}(t) = \begin{cases} \frac{1}{T_u} & |t| \leq \frac{T_u(1-\alpha)}{2} \\ \frac{1}{2T_u}, & \frac{T_u(1-\alpha)}{2} < |t| < \frac{T_u(1+\alpha)}{2} \\ 0, & \text{otherwise} \end{cases} \qquad (9)$$

In the simulation model, the parameter a_1 of SOCW pulse is chosen to be $a_1 = 0.4$, and the parameter set bi of polynomial pulse is chosen to be $\{b_0 = 1, b_1 = -6.625, b_2 = 40, b_3 = -100, b_4 = 85\}$, as proposed in [15] and [16], respectively.

A family of polynomial pulses with small side lobe amplitudes is used in the comparisons; these pulses are characterized by asymptotic decay rate of t^{-2}. The frequency domain of various Nyquist pulses, with α = 0.25 are shown in Figure 2.

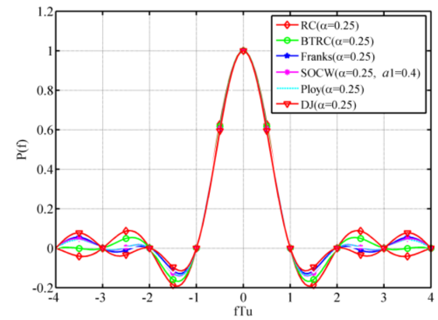


Figure 2 Various Nyquist pulses in the frequency domain

4.0 ICI COMPARISON

We consider an *N*-subcarrier COFDM system with the utilization of pulse shaping over AWGN channel in the present of CFO. The ICI power on the *m*th subcarrier can be defined as [11].

$$\overline{\sigma_{ICI_m}^2} = E[\sigma_{ICI}^2] = \sum_{\substack{k=0 \\ k\neq m}}^{N-1} \left| P\left(\frac{k-m}{T_u} + \Delta f\right) \right|^2 \tag{10}$$

where $P(f)$ is frequency domain response of the pulse shape $p(t)$, and Δf ($\Delta f \geq 0$) is the CFO between the transmitter and the receiver.

According to (10), one can sees that the average ICI power for the *m*th symbol depends on the value of frequency offset, the number of subcarriers, and on the spectral magnitudes of the pulse-shaping function at the frequencies $(((k-m)/Tu) + \Delta f)$, $m \neq k$, $k = 0, 1, ,N\text{-}1$. In case of $\Delta f = 0$, the spectra of the pulses have nulls at the frequencies $(k-m)/Tu$, $m \neq k$, hence no ICI will occur. However, in case of $\Delta f \neq 0$, the spectra of the pulses do not have nulls at the frequency points $(k-m)/Tu)$, $m \neq k$, hence ICI will occur. Therefore, it's expected that a pulse which has spectrum with smaller side-lobes than other pulses will be more efficient in term of ICI power reduction relative to other pulses. In Figure 2, one can observe that the Franks and DJ pulses have the smallest side-lobe among other pulses. Therefore, it's expected that these pulses will be more efficient in term of ICI power reduction compare with other pulses, and consequently the best in term of BER performance improvement.

A comparison of ICI power as a function of the normalized carrier frequency offset, for OFDM system with various pulse shaping is shown in Figure 3. In this comparison the FFT size is 64 and the used subcarrier is 52, the roll off factor is 0.25, and the selected subcarrier index (*m*) is 32. Figure 3 shows the ICI power of various Nyquist pulses, and one can observe that, Franks and DJ pulses have quite similar performance and outperform other pulses. Also, in the same figure when $\Delta f T_u = 0.15$, one can observe that Franks pulse can achieve a 1.77 dB ICI gain over the raised cosine pulse.

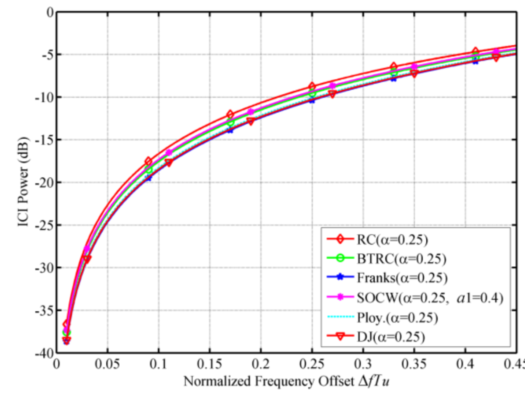


Figure 3 The average ICI power for pulse shaped 64-subcarrier COFDM system with α = 0.25

5.0 SIMULATION RESULTS AND DISCUSSION

In this section, simulation results are presented where a 64-subcarrier COFDM system with various Nyquist pulse-shaping are investigated in term of BER performances. Pulse-shaping, modulation schemes, and coding techniques listed in Table 1 are evaluated on AWGN channel in the presents of CFO.

The BER versus *Eb*/*N*o for a Binary Phase Shift Keying (BPSK)-OFDM system with various pulse- shaping is shown in Figure 4. In the case $\Delta fTu = 0.27$, Franks pulse can achieve about 8.24 dB gain in E_b/N_o at BER of 10^{-4}over the raised cosine.

Table 1 Simulated pulse-shaping, modulation schemes and coding

Pulse-shaping ($\alpha = 0.25$)	Modulation schemes	RS code	CC code
RC BTRC Franks SOCW Poly DJ	BPSK QPSK 16-QAM	(255,239,8)	1/2

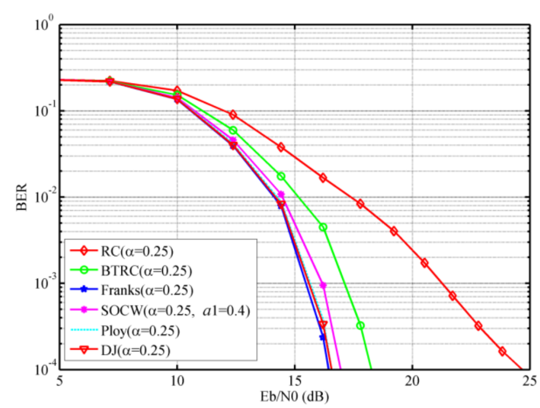


Figure 4 The BER of pulse shaped BPSK-COFDM with α = 0.25 in case $\Delta fTu = 0.27$

Figure 5 shows the BER performance versus E_b/N_o for a Quadrature Phase Shift Keying (QPSK)-OFDM. In the case of $\Delta fTu = 0.13$, one can see that, Franks pulse can achieve about 2.42 dB gain in E_b/N_o at BER of 10^{-4} over the raised-cosine. In addition, Figure 6 shows the BER performance versus E_b/N_o for a 16-Quadrature Amplitude Modulation (16QAM)-OFDM system.

In the case of ΔfTu = 0.05, one can see that, Franks pulse can achieve about 0.38 dB gain in E_b/N_o at BER of 10^{-4} over the raised-cosine.

■6.0 CONCLUSION

A performance of pulse shaped coded OFDM system with carrier frequency offset in AWGN is investigated simulation results showed that Franks pulse outperforms all the previously reported Nyquist pulses in BER. Numerical results showed that Franks pulse and DJ pulse are quite similar, and outperform other Nyquist pulses considered here in term of ICI power reduction, where these two pulses have the smallest side-lobe among other pulses consider here.

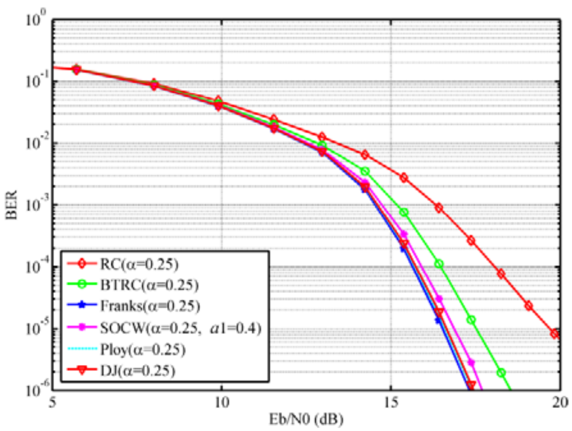


Figure 5 The BER of pulse shaped QPSK-COFDM with α = 0.25 in case ΔfTu = 0.13

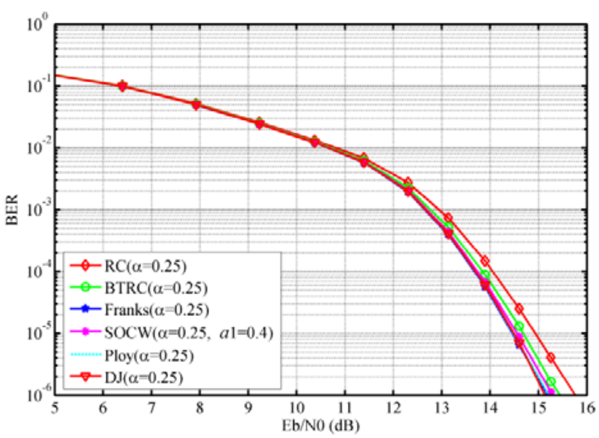


Figure 6 The BER of pulse shaped 16QAM-COFDM with α = 0.25 in case ΔfTu = 0.05

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References

[1] W. Chin-Liang, H. Yu-Chih, and S. Po-Chung. 2006. An Intercarrier Interference Suppression Technique Using Time-Domain Windowing for OFDM Systems. Proc. VTC' 06. 2518.

[2] J. Armstrong. 1999. Analysis of New and Existing Methods of Reducing Intercarrier Interference Due to Carrier Frequency Offset in OFDM. *IEEE Transactions on Communications*. 47(3): 365.

[3] K. Sathananthan and C. Tellambura. 2001. Performance Analysis of an OFDM System with Carrier Frequency Offset and Phase Noise. Proc. VTC'01. 2329.

[4] M. X. Chang. 2004. A Novel Algorithm of Inter-Subchannel Interference Cancellation in OFDM Systems. Proc. VTC'04. 460.

[5] Y. P. Zhao and S. G. Haggman. 2001. Intercarrier Interference Self-Cancellation Scheme for OFDM Mobile Communication Systems. *IEEE Transactions on Communications*. 49(7): 1185.

[6] S. H. Muller-Weinfurtner. 2001. Optimum Nyquist Windowing in OFDM Receivers. *IEEE Transactions on Communications*. 49(3): 417.

[7] N. Al-Dhahir and J. Cioffi. 1994. Optimum Finite-Length Equalization for Multicarrier Transceivers. Proc. GLOBECOM '94. 1884.

[8] H. A. M. Mourad. 2007. Reducing ICI in OFDM Systems Using a Proposed Pulse Shape. *Wireless Personal Communications*. 40(1): 41.

[9] J. Ahn and H. S. Lee. 1993. Frequency Domain Equalisation of OFDM Signals over Frequency Nonselective Rayleigh Fading Channels. *Electronics Letters*. 29(16): 1476.

[10] D. Kang and S. Rongfang. 2006. Second Order Polynomial Class of Nyquist Windows for Reduction of ICI in OFDM Systems. Proc. WiCOM'06. 1.

[11] V. Kumbasar and O. Kucur. 2007. ICI Reduction in OFDM Systems by Using Improved Sinc Power Pulse. *Digital Signal Processing*. 17(6): 997.

[12] C. Berrou and A. Glavieux. 1996. Near Optimum Error Correcting Coding and Decoding: Turbo-Codes. *IEEE Transactions on Communications*. 44(10): 1261.

[13] IEEE 802.16-2004. 2004. IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems.

[14] P. Tan and N. C. Beaulieu. 2009. Analysis of the Effects of Nyquist Pulse-Shaping on the Performance of OFDM Systems with Carrier Frequency Offset. *European Transactions on Telecommunications*. 20(1): 9.

[15] P. Sandeep, S. Chandan, and A. K. Chaturvedi. 2005. ISI-Free Pulses with Reduced Sensitivity to Timing Errors. *IEEE Communications Letters*. 9(4): 292.

[16] S. Chandan, P. Sandeep, and A. K. Chaturvedi. 2005. A Family of ISI-Free Polynomial Pulses. *IEEE Communications Letters*. 9(6): 496.