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INTER CARRIER INTERFERENCE AND SIGNAL TO INTERFERENCE RATIO OF VARIOUS PULSE SHAPING FUNCTIONS USED IN OFDM SYSTEM WITH CARRIER FREQUENCY OFFSET

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Abstract- Orthogonal Frequency Division Multiplexing (OFDM) is the important modulation of choice for fourthgeneration broadband multimedia wireless systems. This paper is focused on the problem of reducing the intercarrierinterference (ICI) and signal to noise ratio in the transmission over OFDM using various pulse shaping methods. Here we have performed a detailed performance comparison of various pulse shaping functions used in OFDM System with Carrier Frequency Offset. They appear to be suitable for transmission in OFDM systems with carrier frequency offset. The results obtained by analysis show that the performance improvement over conventional pulse shapes, are significant for reducing average intercarrier-interference (ICI) power and increased ratio of average signal power to average ICI power (SIR).

Keywords: OFDM; ICI; SIR; ISI; Pulse shaping; Carrier frequency offset

1. INTRODUCTION

The OFDM technique became a very popular method for communications applications. For high data rate applications, in a single-carrier modulated system the effect of the interfering symbols can increase The principle of multi-carrier significantly. transmission is to convert a serial high-rate data stream into multiple parallel low-rate sub-streams. Each sub-stream is modulated by another sub-carrier. Since the symbol rate on each sub carrier is much less than the initial serial data symbol rate, the effects of ISI decrease significantly. The main benefit for a multi-carrier transmission system based on OFDM is that the channel can be considered as time-invariant during one OFDM symbol and that the frequency selective fading per sub-channel can be considered nearly flat fading channels. As further advantages for using OFDM one could also mention high spectral efficiency due to early rectangular frequency spectrum for high numbers of sub-carriers and that multi-carrier modulation can be implemented in the discrete domain by using IDFT, or a more computationally efficient IFFT. Recently, orthogonal frequency division multiplexing (OFDM) has received considerable attention due to the need of high speed data transmission and been accepted as standard in several wire line and wireless applications [1]. One of the main advantages of OFDM is its ability to convert a frequency selective fading channel into several nearly flat fading channels[1].however, one of the main disadvantages of OFDM is its sensitivity against carrier frequency offset which causes attenuation and rotation of subcarriers, and intercarrier interference (ICI) [2,3].

The undesired ICI degrades the performance which is examined in [4]. Several methods have been

presented to reduce ICI, including self-cancellation schemes [5], frequency domain equalization [6], windowing at the receiver [7-9], a number of methods have been developed to reduce the inter-carrier interference. New pulse shaping techniques have been introduced recently [1, 2, 4, 5, 6, 7, 8, and 9]. In this orthogonal frequency-division multiplexing (OFDM) is sensitive to carrier frequency offset which introduces intercarrier interference (ICI) in OFDM receivers. Frequency offset can be compensated by frequency offset estimation. However, estimation error is inevitable, and residue frequency offset usually exists in OFDM systems. Therefore, it is of interest to investigate schemes that are robust to frequency offset. ICI reduction techniques using coding were studied in References [11-14]. Transmitter pulse shaping can also realize ICI power reduction. As classified [15], three types of pulse shaping have been examined in the literature for ICI reduction. The first type, pulses of infinite time duration, was studied in References [16-21]. References [16-18] considered band-limited Nyquist pulses in multichannel data transmission systems. The pulse is chosen as g (t) = F-1{ $\sqrt{G(f)}$ where G (f) is a band-limited Nyquist filter with roll-off factor 'a' and F-1 $\{\cdot\}$ denotes the inverse Fourier transform. Other infinite duration pulses were designed in References [19–21] under the framework of the Weyl-Heisenberg system of functions. The second type comprises pulses of finite duration with length longer than one OFDM symbol interval. These pulses were developed for an OFDM system employing QAM in an AWGN environment based on an optimization criterion which maximizes the in-band Inter carrier Interference and Signal to Interference Ratio of Various Pulse Shaping Functions Used in OFDM System with Carrier Frequency Offset

energy under the constraint of zero inter-symbol interference (ISI) and ICI [15]. The third category also consists of pulses of finite duration. But different from the second category, the pulses have specified length of one OFDM symbol interval. These pulses are usually chosen as Nyquist pulses in the time domain, that is G(t). In this regard, Reference [22] used a raised-cosine pulse in their time-limited orthogonal multicarrier modulation schemes.

1.1 Pulse Shaping Functions

1. Rectangle Pulse

$$p_r(t) = \sin c(tT)$$

2. Raised Cosine Pulse

$$p_{rc}(t) = \frac{\sin c (tT) \cos (\pi a tT)}{(1 - (2 a tT)^2)}$$

3. Better Than Raised Cosine Pulse

$$p_{btrc}(t) = e^{(-a(tT)^2)} \sin c^n (\pi tT)$$

4. Square Root Raised Cosine Pulse

$$p_{srrc}(t) = \sin c(tT)((\frac{4a}{\pi\sqrt{t}}\cos((1+a)\frac{\pi t}{T}))$$
$$+ \frac{(\frac{T}{4at})\sin((1-a)\frac{\pi a}{T})}{(1-(\frac{4at}{T})^2)}$$
5. Polynomial Pulse

$$p_{poby}(t) = \sin c(tT)(1 + \frac{b_3}{4} + \frac{b_4}{8})\sin c^2(\frac{at}{2T})$$
$$+ \frac{\frac{3}{2}b_3(\sin c(atT) - 1)}{(\pi atT)^2} + \frac{\frac{3}{8}b_4(\sin c^2(atT/2) - 1)}{(\pi atT/2)^2}$$

6. Double Jump Pulse

$$p_{di}(t) = \sin c(tT) \cos(\pi a tT)$$

7. Second Order Continuous Window

$$p_{socw}(t) = \sin c(tT) \{ 2(1+b_1) \sin c(atT) -(1+2b_1) \sin c^2(atT/2) \}$$

where; $b_1 = -0.5 \Rightarrow a = 1, b_1 = 0.4 \Rightarrow a = 0.25$

8. Improved Sinc Power Pulse

$$p_{isp}(t) = e^{(-a(tT)^2)} \sin c^n (\pi tT)$$

9. Frank Pulse

$$P_f(t) = \sin c(tT) \{ (1-a)\cos(\pi a tT) + a\sin c(a tT) \}$$

10. Sinc Power Pulse

$$p_{spp}(t) = \sin c(tT) \sin c(tT)$$

2. SYSTEM MODEL

The complex envelope of one radio frequency (RF) N-subcarrier OFDM symbol with pulse-shaping is expressed in [23],

$$x(t) = \exp(j \ 2 \Pi f_c t) \sum_{k=0}^{N-1} D_k P(t) \ \exp(j \ 2 \Pi f_k t)$$
(1)

Where 'f_c' is the carrier frequency system 'f_k' is the subcarrier frequency of the 'k_{th}' subcarrier where k = 0, 1... N-1, etc..., 'p (t)' is the time-limited pulse-shaping function and 'D_k' is the data symbol transmitted on the 'k_{th}' subcarrier. We assume that the transmitted symbol 'D_k' has mean zero and normalized average symbol energy. We further assume that the data symbols are uncorrelated.

$$E[D_{k}D_{m}^{*}] = \begin{cases} 1, k = m \\ 0, k \neq m \end{cases}.$$
 (2)

Where D_{m}^{*} is the complex conjugate of ' D_{m} ' ensure the subcarrier orthogonality, which is very important for OFDM systems the equation below has to be satisfied [10]

$$f_{k} - f_{m} = \frac{(k - m)}{T}$$
(3)

Where k,m = 1,2,...,N-1, '1/T' is the minimum required subcarrier frequency spacing to satisfy orthogonality between subcarriers. Therefore, subcarrier frequencies should be defined as

$$f_{k} = \frac{k}{T}$$
(4)

Where $k = 1, 2, \dots, N-1$. To ensure the orthogonality [24] i.e.

$$\int_{-\infty}^{+\infty} P(t) \exp(j \ 2 \ \Pi(f_k - f_m) \ t) \ dt = \begin{cases} 1, \ k = m \\ 0, \ k \neq m \end{cases}$$
(5)

Equation (5) also indicates the important condition that the Fourier transform of the pulse 'p (t)' should have spectral nulls at the frequencies $\pm 1/(T)$, $\pm 2/(T)$, to ensure subcarrier orthogonality. We consider here various time-limited Nyquist pulses in the time domain Time delayed version of p (t) is

$$P^{d}(t) = P(t - \frac{T}{2}(1 + \alpha)), 0 \le t \le T(1 + \alpha)$$
(6)

The Fourier transform of ' p^d (t) 'is

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$$P^{d}(f) = P(f) \exp(-j\Pi fT (1 + \alpha))$$
 (7)

In the receiver block, the received signal can be expressed as

$$\mathbf{r}(t) = \mathbf{x}(t) \otimes \mathbf{h}(t) + \mathbf{n}(t) \tag{8}$$

Where \otimes denotes convolution and 'h (t)' is the channel impulse response. In (8), 'n (t)' is the additive complex Gaussian noise process with zero mean and variance 'N₀/2' per dimension. For this work we assume that the channel is ideal, i.e., 'h (t) = δ (t)' in order to investigate the effect of the frequency offset only on the ICI performance. At the receiver, the received signal 'r (t)' becomes

$$\mathbf{r}'(t) = \exp(j2\Pi\Delta ft) \sum_{k=0}^{N-1} D_k P(t) \exp(j2\Pi f_k t)$$

$$+ \mathbf{n}(t) \exp(j2\Pi(-f_c + \Delta f)t))$$
(9)

Where Δf ($\Delta f \ge 0$) is the carrier frequency offset between transmitter and receiver oscillators. For the transmitted symbol 'D_m', the decision variable is given as [23]

$$D(t) = \int_{-\infty}^{+\infty} r'(t) \exp(-j 2 \Pi f_{m} t) dt$$
 (10)

3. ICI AND SIR ANALYSIS

To study the effect of different pulse-shaping's on the ICI reduction of an OFDM system in the presence of frequency offset, we consider an imperfect receiver with frequency offset, $\Delta f(\Delta f \ge 0)$, operating on an ideal AWGN channel in the following analysis. The frequency offset may come from the receiver crystal oscillator inaccuracy, residual frequency offset after frequency offset estimation or Doppler shift introduced by the time variation in one OFDM symbol. ISI is not encountered in the AWGN channel model, so it is not necessary to employ a guard interval here. The received signal after multiplication by 'exp (-j 2π (f_c - Δ f) t' becomes. By using (3) and (10), the decision variable can be expressed as N-1

$$D(m) = D_m P(-\Delta f) + \sum_{\substack{k=0\\k\neq m}} D_k P((k-m)/T + \Delta f)$$
$$\times \exp((j\Pi(k-m) + \Delta fT)(1+\alpha)) + N_m$$
(11)

Where 'P (f)' is the Fourier transform of 'p (t)' and N_m , m = 0. . . N - 1 is the independent complex Gaussian noise component in (11). First term contains the desired signal component and the second term represents the ICI component. With respect to (3), 'P (f)' should have spectral nulls at the frequencies \pm

(1/T), \pm (2/T) to ensure subcarrier orthogonality. Then, there exists no ICI term if f and θ are zero. The power of the desired signal can be calculated as [12]

$$\sigma(m)^{2} = E[D_{m}P(-\Delta f) D_{m}^{*}P(-\Delta f)^{*}]$$

$$= E[D_{m}D_{m}^{*}] |P(\Delta f)|^{2} = |P(\Delta f)|^{2}$$
(12)

The power of the ICI can be stated as [13]

$$\sigma(ici)^{2} = \sum_{k=0}^{N-1} \sum_{n=0}^{N-1} [D_{n} D_{k}^{*}] [P((k-m)/T + \Delta f) \times P((k-m)/T + \Delta f)]$$
(13)

The average ICI power across different sequences can be calculated as (13)

$$\sigma(ici)^{2} = E[\sigma[ici))^{2}] = \sum_{\substack{k=0 \ k \neq m}}^{N-1} |P((k-m)/T + \Delta f)|^{2}$$
(14)

As seen in (14) the average ICI power depends on the number of the subcarriers and 'P (f)' at frequencies $((k-m)/T) + \Delta f)$, $k \neq m$. By using (12) and (14), the signal-to-interference ratio (SIR) can be defined as

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

(15)

4. SIMULATION RESULTS



Figure 1. Time Domain Response for all pulses (for a=0.25, where' a' is the roll off factor)



Figure 2. Normalized Frequency Offset (vs.). Intermarries Interference Ratio for ten pulses out of those improved sinc power pulse and Square root raised cosine pulse gives the better performance than remaining pulses (a=0.25, where' a' is the roll off factor)

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Figure 3. Normalized Frequency Offset (vs.). Signal to Interference Ratio for ten pulses out of those improved sinc power pulse and Square root raised cosine pulse gives the better performance than remaining pulses (a=0.25, where 'a' is the roll off factor.

5. CONCLUSION

In this paper, the effect of several Nyquist pulses for ICI reduction and SIR enhancement of OFDM systems in the presence of frequency offset was examined. It was found that the improved sinc power pulse and square root raised cosine pulse exhibits best performance among the Nyquist pulses.

REFERENCES

- S. Hara, R. Prasad, Multicarrier Techniques for 4G Mobile communications, Artech House, Norwood, MA, 2003.
- [2]. J. Armstrong, Analysis of new and existing methods of reducing intercarrier interference due to carrier frequency offset in OFDM, IEEE Trans. Commun. 47 (3) (1999) 365– 369.
- [3]. P.H. Moose, A technique for orthogonal frequency division multiplexing frequency offset correction, IEEE Trans. Commun. 42 (10) (1994) 2908–2914.
- [4]. T. Pollet, M.V. Bladel, M. Moeneclaey, BER sensitivity of OFDM systems to carrier frequency offset and Wiener phase noise, IEEE Trans. Commun. 43 (2–4) (1995) 191–193.
- [5]. Y. Zhao, S.G. Haggman, Intercarrier interference selfcancellation scheme for OFDM mobile communication systems, IEEE Trans. Commun. 49 (7) (2001) 1185–1191.
- [6]. J. Ahn, H.S. Lee, Frequency domain equalization of OFDM signal over frequency nonselective Rayleigh fading channels, Electron. Lett. 29 (16) (1993) 1476–1477.
- [7]. C. Muschallik, Improving an OFDM reception using an adaptive Nyquist windowing, IEEE Trans. Consum. Electron. 42 (3) (1996) 259–269.
- [8]. S.H. Müller-Weinfurtner, Optimum Nyquist windowing in OFDM receivers, IEEE Trans. Commun. 49 (3) (2001) 417– 420.
- [9]. R. Song, S.-H. Leung, A novel OFDM receiver with second order polynomial Nyquist window function, IEEE Commun. Lett. 9 (5) (2005) 391–393.
- [10]. P. Tan, N.C. Beaulieu, Reduced ICI in OFDM systems using the better than raised-cosine pulse, IEEE Commun. Lett. 8 (3) (2004) 135–137.
- [11]. Zhao Y, Leclercq J, H^aaggman S. Intercarrier interference compression in OFDM communication systems by using correlative coding. IEEE Communications Letters 1998; 2(8):214–216.

- [12]. Armstrong J. Analysis of new and existing methods of reducing Intercarrier interference due to carrier frequency offset in OFDM. IEEE Transactions on Communications 1999; 47(3):365–369.
- [13]. ZhaoY, H^{*}aggman S. Intercarrier interference selfcancellation scheme for OFDM mobile communication systems. IEEE Transactions on Communications 2001; 49(7):1185–1191.
- [14]. Zhang H, LiY. Optimum frequency-domain partial response encoding in OFDM system. IEEE Transactions on Communications 2003; 51(7):1064–1068.
- [15]. Vahlin A, Holte N. Optimal finite duration pulses for OFDM. IEEE Transactions on Communications 1996; 44(1):10–14.
- [16]. Chang RW. Synthesis of band-limited orthogonal signals for multichannel data transmission. Bell System Technical Journal 1966; 45(12):1775–1796.
- [17]. Saltzberg BR. Performance of an efficient parallel data transmission System. IEEE Transactions on Communication Technology 1967; 15(12):805–811.
- [18]. Hirosaki B. Orthogonally multiplexed QAM systems using the Discrete Fourier transform. IEEE Transactions on Communications 1981; 29(7):982–989.
- [19]. Haas R, Belefiore JC. A time-frequency well-localized pulse for multiple carrier transmission. Wireless Personal Communications 1997; 5(7):1–18.
- [20]. Kozek W, Molisch AF. Non orthogonal pulse shapes for multicarrier Communications in doubly dispersive channels. IEEE Journal on Selected Areas in Communications 1998; 16(10): 1579–1589.
- [21]. Strohmer T, Beaver S. Optimal OFDM design for timefrequency dispersive channels. IEEE Transactions on Communications 2003; 51(7):1111–1122.
- [22]. Li RY, Stette G. "Time-limited orthogonal multicarrier modulation schemes." IEEE Transactions on Communications 1995; 43(234):1269–1272.
- [23]. Pollet T, Bladel MV, Moeneclaey M. BER sensitivity of OFDM systems to carrier frequency offset and Wiener phase noise. IEEE Transactions on Communications 1995; 43(234):191–193.
- [24]. S. Chandan, P. Sandeep, and A. K. Chaturvedi, Senior Member, A Family of ISI-Free Polynomial Pulses, IEEE COMMUNICATIONS LETTERS, VOL. 9, NO. 6, JUNE 2005.
- [25]. Ziaul Hasan, Umesh Phuyal, V. Yadav, A.K. Chaturvedi, and Vijay K. Bhargava, ISI-free pulses for high-data-rate ultrawideband wireless systems.
- [26]. Antonio Assalini, Student Member, and Andrea M. Tonello, Member, IEEE Improved Nyquist Pulses.
- [27]. Volkan Kumbasar, O^{*}guz Kucur. ICI reduction in OFDM systems by using improved sinc power pulse. ScinceDirect, 2007.
- [28]. Peng Tan and Norman C. Beaulieu European Transactions on Telecommunications Eur. Trans. Telecomms, Analysis of the effects of Nyquist pulse-shaping on the performance of OFDM systems with carrier frequency offset. 2009; 20:9–22.

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