A NEW PULSE SHAPE USED TO REDUCE THE ICI POWER IN OFDM SYSTEMS

Alexandra Ligia Balan[1] and Nicolae Dumitru Alexandru[2]
[1] *Department of Computer, Electronics and Automation, "Ştefan cel Mare" University of Suceava*
Str. Universitatii, no.13, 720229, Suceava, Romania
[2] *Department of Telecommunications, "Gh. Asachi" Technical University of Iaşi, Bd. Carol, I no 11, 700506, Iaşi, Romania*

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Abstract: In this paper we analyze a new pulse shape in order to reduce ICI power in a N-subcarrier OFDM system. The aim is to obtain a small average ICI power and a convenient bit error rate (BER). We focused our paper on three aspects of the analysis, average ICI power, the ratio of average signal power to average ICI power, which is denoted as SIR, and the BER performance for OFDM systems.

1 INTRODUCTION

Orthogonal Frequency Division Multiplexing is a modulation technique used in communication systems. However, a well-known problem in OFDM is its sensitivity to frequency offset errors that destroy the sub-carriers orthogonality, causing a degradation of system performance in terms of inter-carrier interference (ICI).

The OFDM technique uses the principle of multi-carrier transmission to convert a serial high-rate data stream into multiple parallel low-rate sub-streams. Each sub-carrier is modulated by another sub-stream. The symbol rate on each subcarrier is much less than the initial serial data symbol rate and the effects of inter-symbol interference (ISI) decrease significantly.

In order to minimize ICI in OFDM systems, a number of methods have been developed recently. Some of these methods are using new pulse shaping techniques (Tan and Beaulieu, 2004); (Mourad, 2006); (Kumbasar and Kucur, 2007); (Alexandru and Alexandru, 2010).

In the sequel, our paper proposes a new pulse shape used in OFDM systems and investigates its properties exploring inter-carrier interference (ICI) and bit error rate (BER) performance for OFDM systems.

2 PROBLEM STATEMENT

In this section we will briefly review some basic notions used to describe the inter-carrier interference analysis. The OFDM system model and ICI analysis followed the same technique as in the work of Tan and Beaulieu (2004).

The average ICI power, (Tan and Beaulieu, 2004); (Kumbasar and Kucur, 2007), averaged across different sequences is:

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

The average ICI power depends not only on the desired symbol location, m, and the transmitted symbol sequence, but also on the pulse-shaping function at the frequencies $(((k-m)/T)+\Delta f)$, $k \neq m$, $k = 0,1,\ldots,N-1$ and the number of subcarriers.

The ratio of average signal power to average *ICI* power is denoted as signal-to-interference ratio *SIR*, (Tan and Beaulieu, 2004; Kumbasar and Kucur, 2007) and is expressed as

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

Besides the ICI power (P_{ICI}), BER also has an important role in evaluating the performance of an

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OFDM communications system. It is desirable to obtain a balance between a small P_{ICI} and also a satisfactory BER, having as a result an efficient pulse.

A detailed analysis of the BER performance for OFDM systems is presented by Khoa (2008). The expressions of the bit error rate (BER) are derived using a BPSK transmission and an OFDM system with BPSK modulation over the AWGN channel. Based on the analysis performed in the work of Khoa (2008), the BER of an OFDM system can be obtained as a function of frequency offset, Δf $(\Delta f \geq 0)$, phase error θ, average ICI power and $P(f)$. The OFDM system model is proposed by Tan and Beaulieu (2004) employing BPSK modulation over the AWGN channel.

Kumbasar and Kucur (2007) have proposed a new pulse shaping function to reduce ICI in OFDM systems and denoted as *improved sinc power pulse* (ISP). Numerical and simulation results show that the ISP pulse shape, which is a modification of SP pulse (Mourad, 2006), provides a good improvement regarding ICI power, as compared to previously reported pulse shapes.

Recently we have proposed (Alexandru and Onofrei, 2010) a new type of pulse that is a generalization of ISP pulse defined by Kumbasar and Kucur, (2007). Its Fourier transform can be used to decrease ICI in OFDM systems. To define the new shape a generalized formula for $P(f)$ was used

$$P_{SM}(f) = \exp\left\{-a(fT)^2\right\}\left\{\frac{\sin((\pi f - b\sin(c\pi f))T)}{(\pi f - b\sin(c\pi f))T}\right\}^n \quad (3)$$

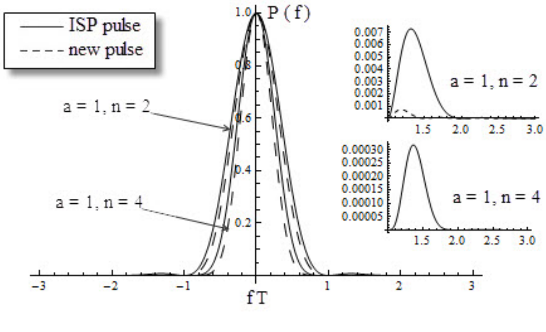


Figure 1: Comparison of ISP pulse shape and the new pulse shape.

3 PULSE CHARACTERISTICS

Based on our earlier studies and analysis we propose a new pulse shape used to obtain improved performance with respect to the reduction of average ICI power of a N-subcarrier OFDM systems.

To construct the new pulse we started from the pulse shape proposed by Jayasimha and Singh, (2000). The new pulse shape is defined in the frequency domain as:

$$H(f) = \left(\frac{\mathrm{sinc}(2\pi fT)}{(1-4f^2)}\right)^n \quad (4)$$

The new proposed pulse is plotted in Figure 1 together with the ISP pulse for different values of the parameters. A closer look reveals that the tails of the new pulse are smaller. Therefore we expect to obtain improved performance in term of ICI analysis.

4 SIMULATION RESULTS AND DISCUSSIONS

In this section we illustrate the performance of the new proposed pulse and compare it with results recently reported in literature. Using the recently proposed techniques for ICI and BER analysis (Tan and Beaulieu, 2004); (Kumbasar and Kucur, 2007); (Khoa, 2008), we study the performance of the new pulses in a 64-subcarrier OFDM-BPSK communication system.

4.1 ICI Analysis

In the sequel we followed the same model presented by Tan and Beaulieu (2004), to evaluate the average *ICI* power and the average signal power to average *ICI* power ratio (*SIR*). The simulations results are obtained for a 64-subcarrier OFDM system.

4.1.1 The Average ICI Power

In order to observe the improvements achieved for the new pulse, in term of average ICI power, we study its behavior compared with ISP pulses taken as a reference.

The results obtained from average *ICI* power analysis are presented in Figure 2. We observe that performance of the proposed pulses is superior to ISP pulse (Kumbasar and Kucur, 2007).

Figure 2 shows that the proposed pulse outperforms reference pulses in terms of average ICI power, for all the selected values of the parameters. From Figure 2 we observe the decrease in ICI power due to the increase of the *sinc* function degree.

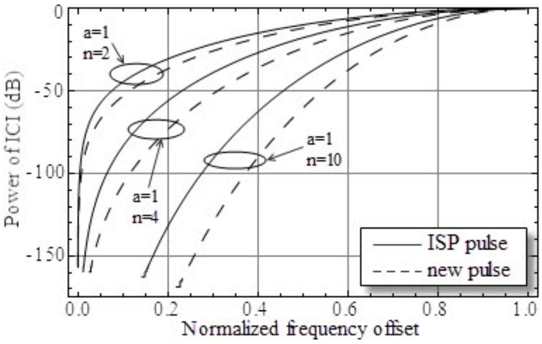


Figure 2: Comparison of average ICI power for the new pulse shape and ISP pulse, in a 64-subcarrier OFDM system.

The variations of average ICI power with sample location *m* are presented in Figure 3. The normalized frequency offset is $\Delta fT = 0.05$.

Studying the results plotted in this figure we observe the decrease in ICI power due to the increase of the *sinc* function degree. The best results were obtained for n=4.

For comparison purposes, we have represented in Figure 3, the ICI power for the new pulse (*n*=2 and *n*=4) together with the rectangular pulse (RP), raised cosine (RC), BTRC (Beaulieu, Tan and Damen, 2001) and ISP (Kumbasar and Kucur, 2007) pulses.

For new pulse (*n*=2), the ICI power is -67.20dB, which is by 46.26 dB better than RP, 34.9 dB better than RC, 27.26 dB better than BTRC, 9.76dB better than ISP (*a*=1, *n*=2).

With respect to the new pulse, with *n*=4, we observed good improvements and the ICI power is -135.98 dB, which is by 115.04 dB better than RP, 103.68 dB better than RC, 96.04 dB better than BTRC, 26.84dB better than ISP (*a*=1, *n*=4).

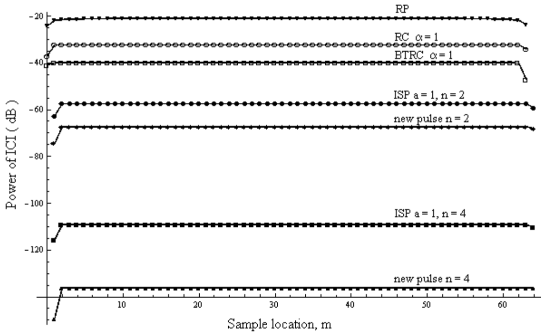


Figure 3: ICI power for different sample locations in a 64-subcarrier OFDM system; ($\Delta fT = 0.05$).

As expected, the ICI drops for the samples located near sample locations *0* and *N-1*, because these samples have fewer interfering samples.

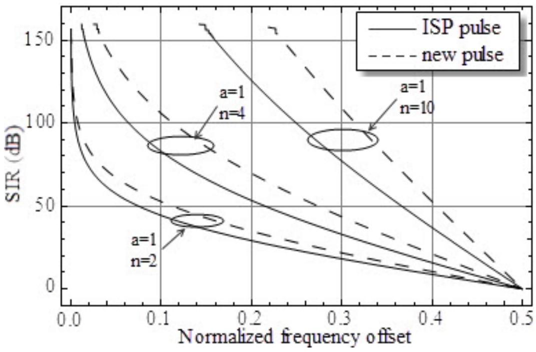


Figure 4: SIR for different pulse shapes in a 64-subcarrier OFDM system.

4.1.2 The Signal-to-interference Ratio SIR

The comparative performances of these pulses in a 64-subcarrier OFDM system in terms of the average signal power to average ICI power ratio, denoted as SIR, are illustrated in Figure 4. Looking at Figure 4, we observe that the results obtained for the SIR ratio show better performance for the new pulse as compared with those obtained for the ISP pulse, which is taken as a reference.

4.2 BER Analysis

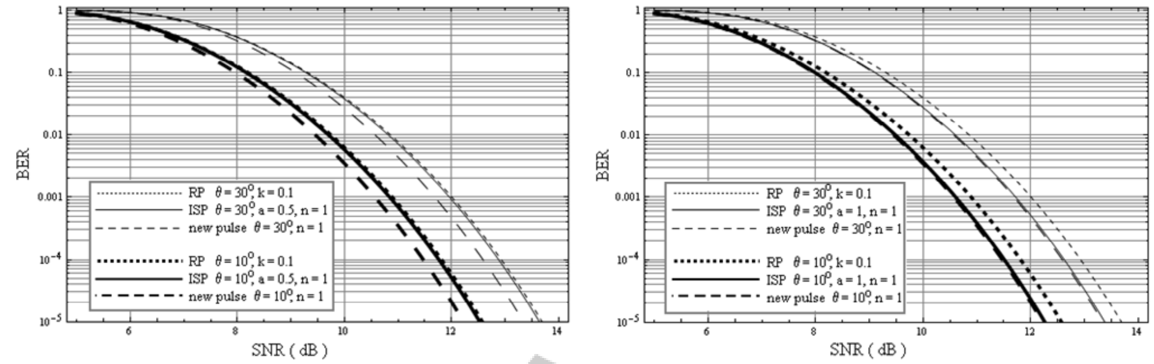
Further, this section investigates the bit error rate (BER) as a function of the signal to noise ratio per bit ($SNR = \gamma_b \overset{\Delta}{=} \frac{E_b}{N_0}$) value.

In Figure 5 it is plotted the BER versus SNR (signal-to-noise ratio) for different values of the parameters *a*, and *n* that are involved in the pulse shape equations. We compared the known ISP pulse and RP pulse with the new pulse shape proposed in this paper.

The effect of the carrier phase noise, θ, in a BPSK-OFDM system with $\Delta fT = 0.1$ is evident. From the results illustrate in the Figure 6, it can be noticed that a smaller carrier phase noise, θ determines an improvement of BER.

From the figures 5a and 5b it can be seen that the proposed pulse exhibits better performance than the reference pulses, when the design parameters are $a = 0.5,\ n = 1$ and $a = 1,\ n = 1$ for ISP pulse and $n = 1$ for the new pulse. We observe that the improvements are visible in the first case presented (Figure 5a). In Figure 5a it is represented with dashed line the results obtained for the new pulse.

The results are better for both cases $\theta = 30^o$ and $\theta = 10^o$ (thicker line). In Figure 5b we observe that



(a) (b)

Figure 5: BER performance of an OFDM-BPSK system using the new proposed pulse, ISP pulse and RP pulse with $\Delta fT = 0.1$, $N = 256$.

the results obtained for the new pulse are also better than the results obtained for the ISP pulse even if improvements are not as obvious as in Figure 6a.

One can notice that the results obtained for the BER versus SNR of an OFDM BPSK system are better or comparable with the results obtained for all reference pulses.

Even if in some cases the obtained results are comparable or slightly worse than those known in the literature we can say that the proposed pulse has theoretical and practical importance because it is characterized by low-complexity and a smaller number of parameters that are involved in pulse shape design.

5 CONCLUSIONS

In this paper we studied the performance of a N-subcarrier OFDM systems in the presence of frequency offset, in terms of ICI and BER performance.

We have investigated a new pulse shape, which according to the analysis performed above presents significant improvements in the reduction of inter-carrier interference (ICI) power caused by the frequency offset. The SIR performance increase with the new pulse shape, as compared to the ISP pulse shape and conventional pulse shapes.

We studied the effects of the carrier phase noise and pulse shaping on BER of an N-subcarrier OFDM-BPSK system as a function of the carrier frequency offset Δf, the carrier phase noise θ, average ICI power and $P(f)$.

It should be pointed out that in this paper we investigated a new pulse characterized by low complexity and a smaller number of parameters that are involved in pulse shape design.

Numerical and simulation results show that the proposed pulse presents theoretical and practical importance.

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