Proceedings of the World Congress on Engineering 2009 Vol I
WCE 2009, July 1 - 3, 2009, London, U.K.

Performance Enhancement of OFDM System with ICI Reduction Technique

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***Abstract*—orthogonal frequency-division multiplexing (OFDM) communication systems, the frequency offsets in mobile radio channels distort the orthogonality between subcarriers resulting in inter-carrier interference (ICI). In this paper, First OFDM system is modeled and simulated under different channel conditions such as AWGN and Rayleigh fading. Subsequently pulse shaping technique for ICI power reduction in OFDM systems is investigated. A number of pulse shaping functions such as Rectangular pulse shape, Sinc power pulse (SP) and Improved sinc power pulse (ISP) have been considered for ICI power reduction. The performance of each pulse shaping function is evaluated and compared with each other using the parameters such as ICI power, SIR (Signal to Interference Ratio) and BER (Bit Error Rate). It is found that ISP pulse shape outperforms to all other pulse shaping functions by the above parameters.**

***Index Terms*— Intercarrier interference, AWGN, Sinc power pulse , Improved Sinc power pulse, Bit Error Rate.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has recently been applied widely in wireless communication systems due to its high data rate transmission capability with high bandwidth efficiency and its robustness to multi-path fading and delay [1,2]. It has been used in digital video broadcasting (DVB) systems, wireless LAN standards such as American IEEE802.11a and the European equivalent HIPERLAN/2 and in multimedia wireless services such as Japanese Multimedia Mobile Access Communications. It has also been proposed as the core technique for the fourth-generation (4G) mobile communications.

The main advantage of the OFDM system is its ability to convert a frequency selective fading channel into several nearly flat fading channels as the entire available spectrum is divided into a number of narrow band sub channels. The high spectral efficiency in the system is obtained by overlapping the orthogonal frequency responses of the sub channels. However, one of the main disadvantages of OFDM is its sensitivity against carrier frequency offset which causes attenuation and rotation of subcarriers, and inter-carrier interference (ICI) [3]. The undesired ICI degrades the performance of the system. It is not possible to make reliable data decisions unless the ICI powers of OFDM systems are minimized. Thus, an accurate and efficient Intercarrier Interference (ICI) reduction procedure is necessary to demodulate the received data.

Several methods have been presented to reduce ICI, including frequency domain equalization [4,5], windowing at the receiver [6,7], ICI self-cancellation scheme [8,9], and the use of pulse shaping [10,11,12]. In this paper ICI reduction using pulse shaping performance are analyzed considered in details.

The paper is organized as follows. In Section II, the OFDM system model is described. In Section III, the ICI power analysis is done. Pulse shaping function are given in Section IV. In section V, the simulation results are described. Section VI concludes the paper.

II. System Description

Figure 1 shows a Fast Fourier transform (FFT) based *N*-subcarrier OFDM system. Here the transmitter block creates the signal x(t) which is transmitted through the channel with pulse shaping. This transmitted signal can be expressed as

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

Where f_c is the carrier frequency of OFDM system, N is the subcarrier number, f_k is the *kth* subcarrier frequency, where $k = 0, 1, \ldots\ldots\ldots\ldots, N-1$, s_k is the data symbol transmitted on the *k*th subcarrier and *p(t)* is the pulse shaping function.

The transmitted symbol s_k is assumed to have zero mean and normalized average symbol energy. Also we assume that all data symbols are uncorrelated, i.e.,

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

Where s^*_m is the complex conjugate of s_m . To ensure the subcarrier orthogonality, which is very important for OFDM systems the equation below has to be satisfied

$$f_k - f_m = \frac{k-m}{T}, \quad k, m = 0,1,\ldots, N-1,$$

(3) where 1/T is the minimum required subcarrier frequency spacing to satisfy orthogonality between subcarriers. Therefore, subcarrier frequencies should be defined as

$$f_k = k/T, \quad k = 0,1,\ldots N-1 \qquad (4)$$

In the receiver block, the received signal is expressed as

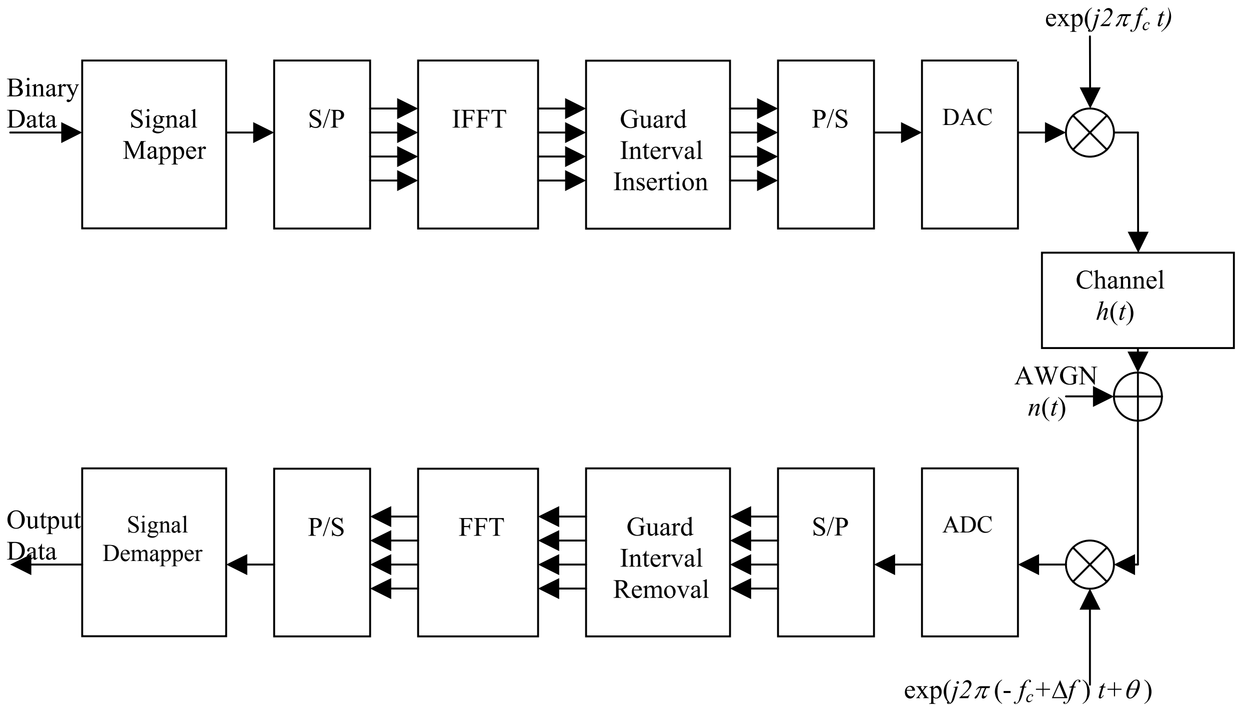

Figure.1. N-Subcarrier OFDM System model

$$r(t) = x(t) \otimes h(t) + n(t) \quad (5)$$

Where ⊗ denotes convolution and $h(t)$ is the channel impulse response. In (5), n(t) is the additive complex Gaussian noise process with zero mean and variance $N_0/2$ per dimension. For this work we assume that the channel is ideal, i.e., $h(t) = \delta(t)$ in order to investigate the effect of the frequency offset only on the ICI performance. At the receiver, the received signal after multiplication by $\exp\{ j(2\pi(-f_c + \Delta f)t + \theta)\}$ becomes

$$\begin{aligned} r'(t) &= \exp\{j(2\pi\Delta f t + \theta)\}\sum_{k=0}^{N-1} s_k p(t)\exp\{j2\pi f_k t\} \\ &\quad + n(t)\exp\{j(2\pi(-f_c + \Delta f)t + \theta)\} \end{aligned} \quad (6)$$

Where θ is the phase error and Δf (Δf≥0) is the carrier frequency offset between transmitter and receiver oscillators.

For the transmitted symbol s_m, the decision variable is given as

$$\hat{s}_m = \int_{-\infty}^{\infty} r'(t)\exp\{-j2\pi f_m t\}\,dt \quad (7)$$

III. ICI ANALYSIS

Putting the value of $r'(t)$ in equation (7), and rearranging it, the decision variable $\hat{s}_m$ can be expressed as

$$\begin{aligned} \hat{s}_m &= \int_{-\infty}^{+\infty} s_m \exp\{j\theta\} p(t)\exp\{j2\pi\Delta f t\}\,dt \\ &+ \int_{-\infty}^{+\infty}\exp\{j\theta\}\sum_{\substack{k=0\\k\neq m}}^{N-1} s_k p(t)\exp\left\{-j2\pi\left(\frac{m-k}{T} - \Delta f\right)t\right\}dt + n_m \end{aligned}$$

(8)

$$= \left(s_m P(-\Delta f) + \sum_{\substack{k=0\\k\neq m}}^{N-1} s_k P\left(\frac{m-k}{T} - \Delta f\right)\right)\exp(j\theta) + n_{m,}$$

(9)

Where $p(-\Delta f) = \int_{-\infty}^{+\infty} p(t)\exp\{j2\pi\Delta f t\}\,dt$

And n_m, $m = 0, N - 1$ is the independent complex Gaussian noise component In (9), the first term contains the desired signal component and the second term represents the ICI component.

The power of the desired signal can be calculated as

$$\sigma_m^2 = E[s_m s_m^*]\left|P(\Delta f)\right|^2 = \left|P(\Delta f)\right|^2$$

(10)

The power of the ICI can be calculated as

$$\sigma_{ICI_m}^2 = \sum_{\substack{k=0\\k\neq m}}^{N-1}\sum_{\substack{n=0\\n\neq m}}^{N-1} s_n s_k^* P\left(\frac{k-m}{T} + \Delta f\right)P\left(\frac{n-m}{T} + \Delta f\right)^* \quad (11)$$

The average ICI power across different sequences can be calculated as

$$\overline{\sigma_{ICI}^2} = E\left[\sigma_{ICI_m}^2\right] = \sum_{\substack{k=0\\k\neq m}}^{N-1}\left|P\left(\frac{k-m}{T} + \Delta f\right)\right|^2 \quad (12)$$

By using (10) and (12), the signal-to-interference ratio (SIR) can be defined as

$$SIR = \frac{\left|P(\Delta f)\right|^2}{\sum_{\substack{k=0\\k\neq m}}^{N-1}\left|P\left(\frac{k-m}{T} + \Delta f\right)\right|^2} \quad (13)$$

IV. PULSE SHAPING FUNCTION

In the OFDM spectrum each carrier consists of a main lobe followed by a number of side lobes with reducing amplitude when orthogonality lost some power of the side lobes exists at the centre of the individual carriers which is ICI power. The ICI power will increase with increase of frequency offset. The purpose of pulse shaping is to reduce the side lobes.

Hence a number of pulse shaping functions such as Rectangular pulse (REC), raised cosine pulse (RC), Better then raised cosine pulse (BTRC), Sinc power pulse (SP) and Improved sinc power pulse (ISP) have been considered for ICI power reduction. Among these pulses we can consider only two pulse shaping function. The functions are defined as below.

Rectangular pulse,

$$P_{REC}(f) = \sin c(fT), \tag{14}$$

Sinc power pulse,

$$P_{SP}(f) = \sin c^{n}(fT), \tag{15}$$

Improved sinc power pulse,

$$P_{ISP}(f) = \exp\{-a(fT)^2\}\text{sinc}^{n}(fT), \tag{16}$$

Where α (0≤α≤1) is the roll off factor and $\beta = \pi\alpha/\ln 2$, 'a' is a design parameter to adjust the amplitude and n is the degree of the sinc function. Below figure 2 shows the spectral comparison of different pulse shape.

The purpose of pulse shaping is to reduce the side lobe, as the side lobe contains the ICI power. The above figure shows that the side lobe is maximum for rectangular pulse and minimum for ISP pulse shapes. This property of ISP pulse shape will provide better performance in terms of ICI reduction than those of the other pulse shapes.

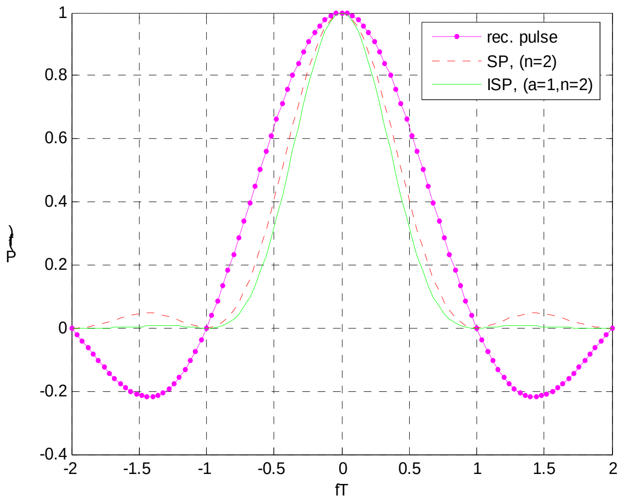

Figure.2. Comparison of SP and ISP pulse

V. SIMULATION RESULT

In the OFDM system can be simulated with 128 sub-carriers, a 4-ms symbol time, and a 1/4symbol time guard interval. After defining the entire variable, QPSK is chosen to be modulation techniques in each channel.

The simulation parameters for the OFDM system under AWGN channel is shown in Table 1. The BER performance of OFDM is compared with the theoretical and simulation under the AWGN channel and Rayleigh fading channel.

Figure 3 shows the BER performances of OFDM under AWGN channels and Rayleigh fading channel. The result derived out of AWGN communication channel is best and ideal performance as compared to Rayleigh fading.

For pulse shaping, the root Nyquist filter is used [13]. The theoretical BER values with AWGN and one-path Rayleigh fading are shown below.

$$BER_{QPSK-AWGN} = \frac{1}{2}erfc\left(\sqrt{E_b/N_0}\right) \tag{17}$$

$$BER_{QPSK-FADING} = \frac{1}{2}\left[1 - \frac{1}{\sqrt{1+\frac{1}{E_b/N_0}}}\right] \tag{18}$$

The ICI power for different sample locations in a 64-subcarrier OFDM system is shown in Figure 4 for normalized frequency offset, ΔfT = 0.05.

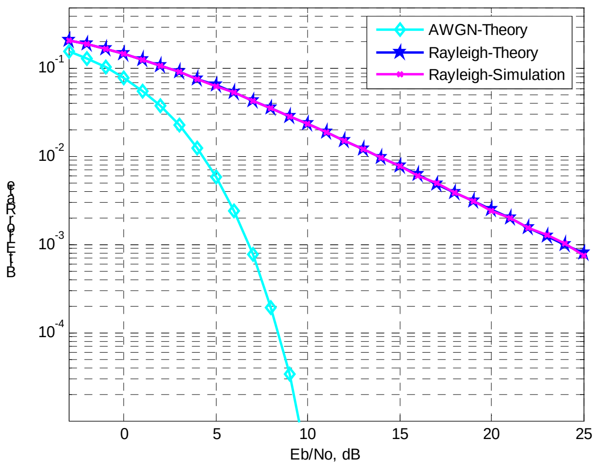

Figure.3.OFDM comparison between AWGN and one path

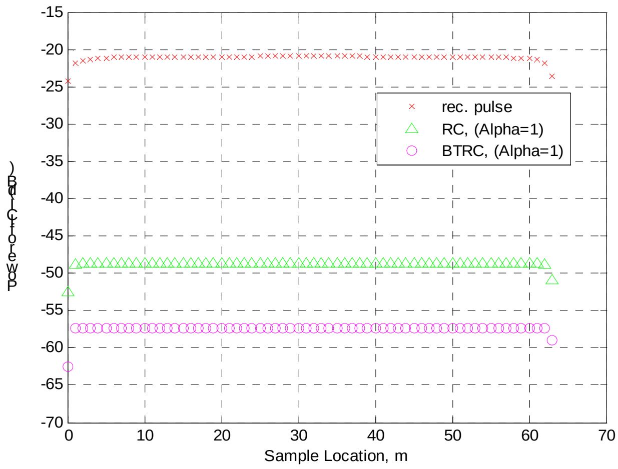

Fig.4. ICI power performance for different pulse shapes

In this figure the pulse shape parameters are chosen as the following; α = 1, n = 2, and a = 1. The results show that for all sample locations the ICI power is minimum for ISP pulse shape compared to other pulse shapes. Fig.4. ICI power performance for different pulse shapes.

Table.1. Simulation Parameters

Parameter	**Specifications**
FFT Size	64
Number of Carriers	64
Guard Length	16
Symbol rate	250000
Signal Constellation	QPSK
Channel	AWGN
OFDM symbols for one loop	12
Number of simulation loops	100

The BER performance of the OFDM system with pulse shaping to that of without pulse shaping is shown in Figure 5. In this figure the pulse shape parameters are selected as, n = 2 and *a* = 1. A normalized frequency offset of 0.25 is considered for both SP, ISP pulse shape and also for the without pulse shaping OFDM system.

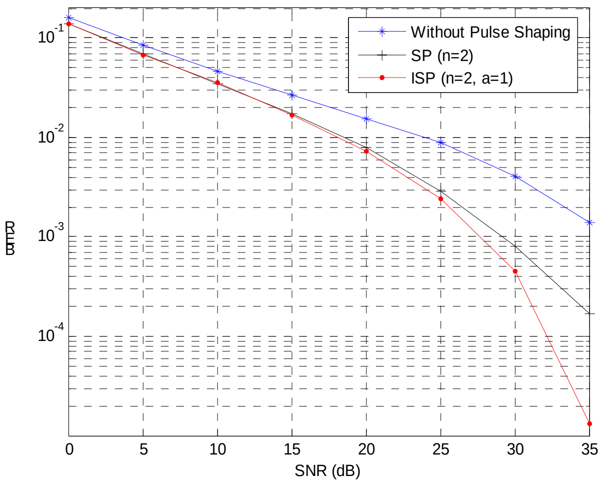

Fig. 5 BER performance of QPSK-OFDM system for ISP &SP with ΔfT=0.25

From the result it is seen that OFDM system with pulse shaping is outperforming to OFDM system without pulse shaping for the entire range of SNR. We can also compare the performance between SP and ISP pulse shapes. It is seen that up to a SNR value of 20 dB both SP and ISP are performing equally. Beyond 20 dB ISP pulse shape outperforming SP pulse shape.

The reason is below 20 dB the additive noise component is high. So within this range the BER performance largely depends on the additive noise component which is much higher than the ICI component. Above 20 dB additive noise component is less, so BER performance largely depends on the ICI component. Here ISP outperforms because the ICI component of ISP is lower than the ICI component of SP as shown in figure 4.

VI. CONCLUSION

A number of pulse shaping functions are considered for ICI power reduction. The performance of each pulse shaping function is evaluated and compared with each other using the parameter such as ICI power, SIR (Signal to Interference Ratio) and BER (Bit Error Rate). Simulation results shows that ISP pulse shapes provides better performance in terms of ICI power reduction, SIR and BER as compared to the conventional pulse shapes. And also AWGN communication channel gives better BER performances over Rayleigh fading channel.

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ISBN: 978-988-17012-5-1