TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 5, October 2020, pp. 2276~2283
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i5.13840

Pulse shaping methods for inter carrier interference reduction in OFDM system

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Article Info

Article history:

Received Aug 8, 2019
Revised Apr 17, 2020
Accepted May 11, 2020

Keywords:

ICI
ISP pulse
OFDM
Pulse shaping
Rectangular pulse

ABSTRACT

The weakness of the orthogonal freuency division multiplexing (OFDM) system is susceptible to the existence of carrier frequency offset (CFO) which causes the emergence of inter carrier interference (ICI) which causes a degradation of performance OFDM systems. This study aims to apply the suggested rectangular (REC) pulse and improved sinc-power (ISP) pulse shaping methods on OFDM system and determines ICI reduction with the effects of CFO over flat fading Rayleigh channels. The performance of each pulse shaping method is evaluated and compared based on parameter ICI power vs. normalized frequency offset, signal to interference ratio (SIR) vs. normalized frequency offset and bit error rate (BER) vs. energy bit per noise (Eb/No). The simulation result in terms of BER vs. Eb/No indicated that REC and ISP pulse shaping has better performance dealing with ICI reduction compared to OFDM system no applied pulse shaping. In addition, the ISP is able to mitigate ICI better than REC.

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1. INTRODUCTION

OFDM is a multicarrier transmission technique which between subcarriers are arranged to be mutually overlapping and arranged in such a way so that between subcarriers will have orthogonal properties [1, 2]. By using this overlapping technique, OFDM systems offer high bandwidth efficiency that save up to 50% [3]. It also has high data rate transmission capability and robust to multipath fading and delay. It able 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 subchannels. Due to its advantages, OFDM has been identified as one of the prime technologies for use in the next generation of heterogeneous wireless networks.

However, one of the main disadvantages of OFDM is its susceptible to carrier frequency offset (CFO) which can arise due to the Doppler effect and frequency mismatches of the transmitter and receiver oscillators. The interference affected by frequency offset will cause orthogonality losses between OFDM scheme's subcarriers and results in the emergence of inter carrier interference (ICI) which can reduce the performance of the OFDM system [4]. Therefore, an action is needed to mitigate ICI in OFDM systems.

Several methods have been introduced to mitigate ICI such as pulse shaping [5-10], frequency domain equalization [11], ICI self-cancellation schemes [12], windowing [13] at the receiver and Maximum likelihood estimation technique (MLE) [14]. In this paper, pulse shaping methods have been considered due to its simplicity and efficiency [15]. The pulse shaping method is the most effective method that can be used to overcome the main causes of ICI in OFDM systems because with the implementation of pulse shaping, the subcarrier will be filtered when it is still mutually orthogonal so that when it arrives at the receiver, the effect of interference from another subcarrier will be reduced [5].

The use of Nyquist-I pulses to reduce the ICI power in OFDM-based systems has been proposed [6, 7, 16, 17] such as the raised cosine (RC) pulse, "better than" raised cosine (BTRC) pulse, sinc power (SP) pulse, improved sinc power (ISP) pulse and rectangular (REC) pulse. Currently, the ISP is probably that has the best performance in dealing with ICI due to frequency offset in OFDM systems. In this paper, the proposed implementation of REC and ISP pulse was proposed with variations of normalized frequency offset. A simulation model for assessing the performance of REC and ISP pulse was introduced using OFDM system in a flat fading Rayleigh channel.

2. RESEARCH METHOD

A simulation method was used to evaluate the performance of REC pulse and ISP pulse in reducing ICI due to frequency offset effects on OFDM system over flat fading Rayleigh channel. Simulations have been performed in order to compare the performance of the OFDM systems, with and without pulse shaping. The performance of REC pulse and ISP pulse were also observed using the variation of normalized frequency offsets. The parametes used to evaluate including ICI power vs. normalized frequency offset, signal to interference ratio (SIR) vs. normalized frequency offset and bit error rate (BER) vs. energy bit per noise (Eb/No).

2.1. Modelling ICI

For system modeling that experiences ICI effect, it is stated in (1) as follows [3].

$$s'_m = \left(s_m P(-\Delta f) + \sum_{\substack{k=0 \\ k\neq m}}^{N-1} s_k P\left(\frac{m-k}{T} - \Delta f\right) \right) e^{j\theta} + n_m \tag{1}$$

The ICI effect on the received symbol is expressed as Δf variable called CFO. The next CFO will be normalized to the subcarrier spacing (Δf_c) which is called the normalized frequency offset (ΔfT). That ΔfT or ε shows how much the subcarrier shifted is detected by the receiver oscillator where |ΔfT|≤1. In the simulation model, the formula is excuted after the output of parallel to serial. The magnitude of the normalized frequency offset used in this paper was calculated using (2) as follows [18]:

$$\varepsilon = \frac{f_{offset}}{\Delta f_c} \tag{2}$$

In this paper, to determine normalized frequency offset variations, we use a set of frequency offset including 2 kHz, 4 kHz and 5 kHz that represent for large and small subcarrier shifted. In accordance with the fixed WiMAX standard, the subcarrier spacing (Δf_c) used was 9765 Hz and using (2), the normalized frequency offset can be found as follows;

Frequency offset = 2 kHz = 2000 Hz
$\varepsilon = \frac{\Delta f}{\Delta f_c} = \frac{2000}{9765} = 0{,}2.$
Frequency offset = 4 kHz, ε = 0.4.
Frequency offset = 5 kHz, ε = 0.5.

ICI power states the magnitude power of ICI that generated from OFDM system after the implementation of pulse shaping to reduce ICI in OFDM systems where the amount of ICI power generated can be calculated using (3) as follows [18].

$$\sigma^2_{ICI_m} = \sum_{\substack{n=0 \\ k\neq 0}}^{N-1} \sum_{\substack{n=0 \\ k\neq 0}}^{N-1} s_m s_n^* P\left(\frac{k-m}{T} - \Delta f\right) P\left(\frac{n-m}{T} - \Delta f\right) \tag{3}$$

Signal to interference ratio (SIR) states the ratio of magnitude of received signal strength to interference between subcarriers. The magnitude of SIR is expressed using (4) as follows [19];

$$\text{SIR} = \frac{|P(\Delta f)|^2}{\sum_{\substack{n=0 \\ k\neq 0}}^{N-1} |P\left(\frac{k-m}{T_0} + \Delta f\right)|^2} \quad (4)$$

2.2. Pulse shaping function

This function acts to form a pulse of existing symbols. Each symbol that is transmitted will be multiplied by pulse shaping function. The use of pulse shaping method is to eliminate the side lobe power which can potentially generate ICI power. So that the use of pulse shaping can reduce ICI power due to the frequency offset [20]. The pulse function in the frequency domain was used in this paper as follows [3].

– REC pulse

$$P_{rec}(f) = sinc(fT) \; , \quad (5)$$

then the frequency offset is substituted to (5)

$$P_{rec}(\Delta f) = sinc(\Delta fT) \quad (6)$$

– ISP pulse

$$P_{ISP}(f) = e^{-a(fT)^2} sinc^n(fT) \quad (7)$$

then the frequency offset is substituted to (7)

$$P_{ISP}(\Delta f) = e^{-a(\Delta fT)^2} sinc^n(\Delta fT) \quad (8)$$

For ISP pulse, there are variables, a and n, according to [21]. The performance improvement of OFDM system can survive if the parameter a = 1 and n = 2. The spectrum of ISP and REC pulse can be seen in Figure 1 [22]. Figure 1 illustrates ISP pulse (in brown line) has the same side lobe power as zero compared to the side lobe of the REC pulse (in blue line). Due to the value of side lobe is zero, then when the subcarrier shifted to the orthogonal position of the side lobe, the interference will not affect the other subcarriers. On the other hand, for REC pulse, the power of the side lobe cannot be maximally reduced due to the subcarrier shifted that will causes interference of other subcarriers [18]. The purpose of using pulse shaping method is to eliminate side lobes that can potentially generate ICI power. The use of ISP pulse can reduce ICI power from the side lobe better than the REC pulse [3].

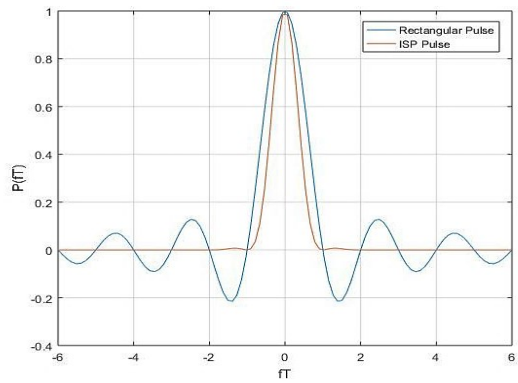

Figure 1. Spectrum of ISP and REC pulse

2.3. Simulation model

We consider ISP dan REC pulse applied to the OFDM system in a flat fading Rayleigh channel as shown in Figure 2 [20, 23, 24]. The pulse shaping function was applied at the transmitter. Flat fading Rayleigh channel was used where each channel response that is Rayleigh distributed [25] with adding addictive white Gaussian noise (AWGN). The parameters used in this simulation were based on fixed wireless worldwide interoperability for microwave access (WiMAX) standard as shown in Table 1.

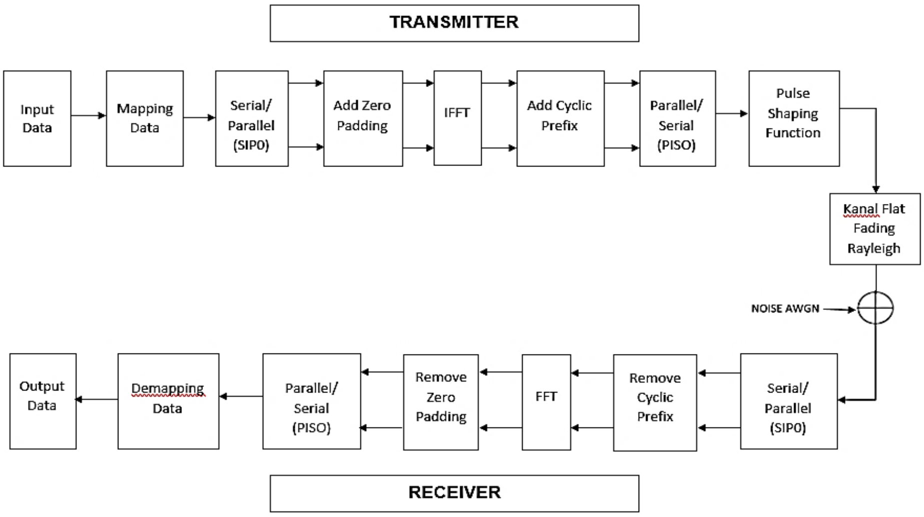

Figure 2. ISP dan REC pulse applied to the OFDM system over flat fading Rayleigh channels

Table 1. Parameter simulation

Parameter	Values
Input Bit	Random 100.000 bits
Type of modulation	QPSK
FFT size	64
Number of subcarriers	64
Number of data subcarriers	52
Cyclic prefix Lengths	16
Type of channel	AWGN + flat fading Rayleigh
Normalized frequency offset (ε)	0.2, 0.4 and 0.5
Frequency offset	2 kHz, 4 kHz, 5 kHz
Subcarrier spacing	9.765 kHz
Eb/No	0:2:20
Pulse shaping	ISP & REC pulse

3. RESULTS AND ANALYSIS

Simulations have been performed in order to evaluate and compare the performance of OFDM systems, with and without pulse shaping, in reducing ICI with effects of CFO. The simulation uses the parameters discussed in section 2.3. The simulation model is presented in Figure 2. We also present performance comparison of REC and ISP pulse using normalized frequency offset variations in order to assess the effects of normalized frequency offset on OFDM system performance. The performance of each pulse shaping method is evaluated and compared based on parameter ICI power vs. normalized frequency offset and signal to interference ratio (SIR) vs. normalized frequency offset. The BER vs. Eb/No performance for OFDM system, with and without pulse shaping, is examined and compared in the case of an AWGN and flat Rayleigh fading channel.

3.1. BER performance with a normalized frequency offset

Figure 3 presents BER performance of OFDM system, with and without pulse shaping, in case of fading channel. Both pulse shaping, REC and ISP pulse, evaluated and compared, in order to investigate the effect of CFO. The normalized frequency offset used was about 0.2. At an Eb/No of 10 dB, the BER for OFDM systems without pulse shaping is about 0.0180 while BER for OFDM systems with REC and ISP were 0.0090 and 0.0056, respectively. The use of pulse shaping has given better performance than OFDM with no pulse shaping. Futhermore, OFDM system performance with applied ISP pulse has shown better performance than REC pulse. This was indicated by the BER performance of ISP pulse lower than REC pulse. It has happened due to ISP pulse affected to the side lobe of each subcarrier to be zero power (flat). When ICI arises, there will be no shifted in subcarriers side lobe. Therefore, the subcarriers do not lose its orthogonality and will not cause interference between subcarriers [26, 27]. Thus, it can be concluded that the use of pulse shaping can provide an increase in OFDM system performance because the interference effects of subcarriers can be minimized using reducing ICI power in side lobe. ISP pulse was able to reduce ICI better than REC pulse.

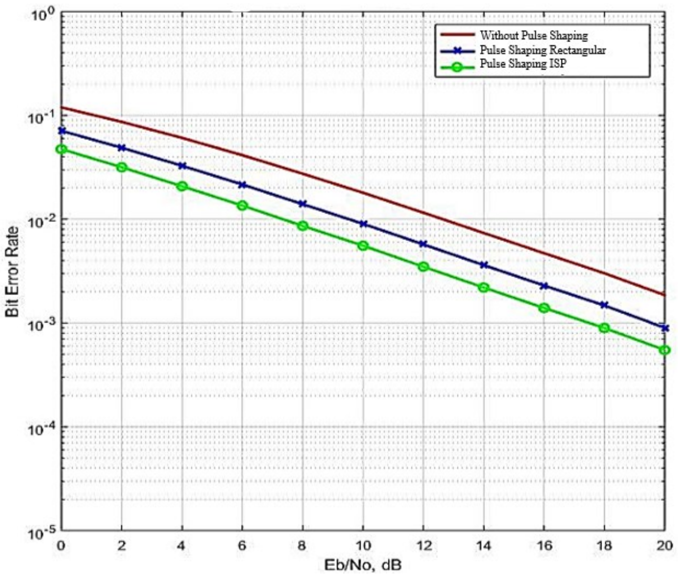

Figure 3. BER vs. Eb/No of OFDM System, without and with REC and ISP pulse

3.2. BER performance with normalized frequency offset variations

Figure 4 depicts BER performance of OFDM system, without and with pulse shaping, using variations of normalized frequency offset. The normalized frequency offset was referred to (2). So, the normalized frequency offset (ε) used in the simulation were 0.2, 0.4 and 0.5. From Figure 4, it can be seen that BER performance comparison of REC and ISP pulse applied to OFDM system, with $\varepsilon = 0.5$, was given the worst BER performance. Normalized frequency offset is expressed as a subcarrier shifted that caused by frequency offset. So that, if the subcarrier frequency shifted or normalized frequency offset is greater, the effect of interference from other subcarriers accordingly will be greater and the ICI power produced will increase. Thus, it can be concluded that the greater the normalized frequency offset, the OFDM system performance will be worse. It is due to the higher the offset frequency effected to the OFDM system so that the ICI power generated will also be greater. From the simulation results, it can also be seen that BER performance of OFDM system with ISP pulse was able provided better performance than REC pulse [25-27].

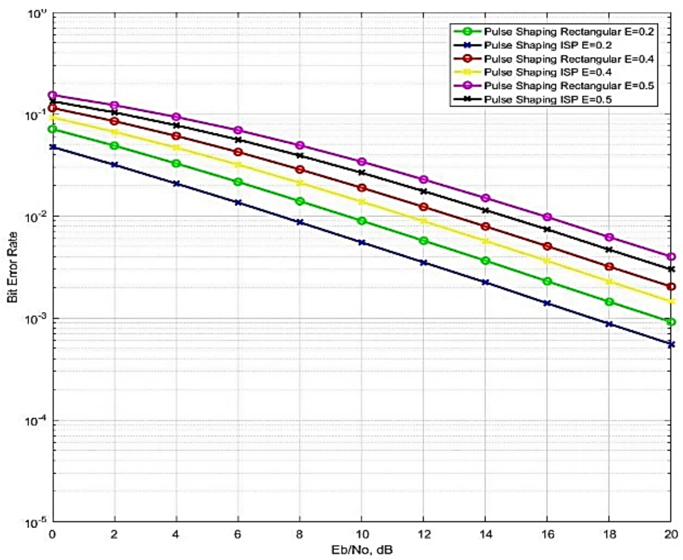

Figure 4. Performance of OFDM system with normalized frequency offset variations

3.3. ICI power and SIR analysis

Refered to the (3) and (4), ICI power and signal to interference ratio (SIR) were generated after the implementation of ISP and REC pulse. The performance of REC and ISP pulse based on parameter ICI power vs. normalized frequency offset and SIR vs. normalized frequency offset, can be illustrated in Figures 5 and 6, respectively. Figure 5 shows that at normalized offset frequency, $\varepsilon = 0.2$, REC pulse applied to OFDM system created ICI power about -10.9723 dB, which is higher than applied ISP pulse to OFDM system, about -42.6542 dB. Important trend can be observed from this simulation result that in highest normalized frequency offset resulting the smallest ICI power. So, ICI power inversely proportional to normalized frequency offset.

From Figure 6, it can be seen that SIR performance for REC pulse applied to OFDM system was smaller than SIR performance for ISP pulse. At $\varepsilon = 0.2$, SIR performance of REC pulse applied to OFDM system was about 13.0045 dB while ISP pulse applied to OFDM system was about 38.0214 dB. The important trend can be observed that SIR performance inversely proportional to normalized frequency offset where the higher normalized frequency offset resulting lower SIR performance.

The higher SIR and smaller ICI power will cause the better performance of OFDM system. The use of ISP pulse can improve OFDM system performance better than REC pulse due to ISP pulse minimizing ICI power better than REC pulse. By minimizing the ICI power, it results the lower risk of orthogonality losses between OFDM scheme's subcarriers. This causes SIR in OFDM system increasing and OFDM system performance tends to be better.

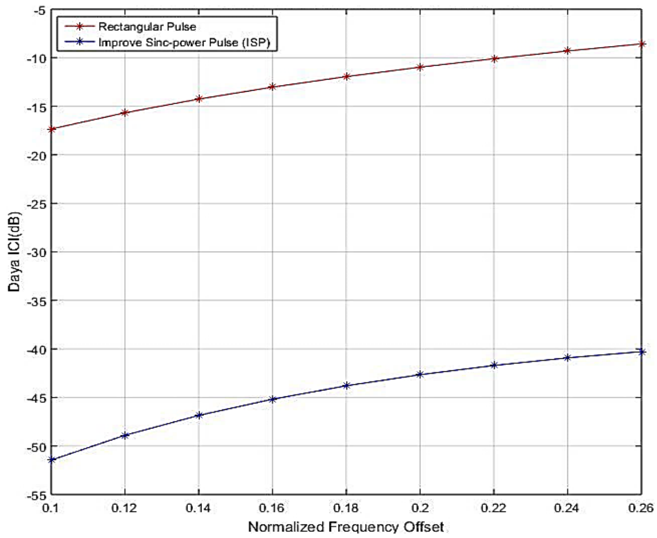

Figure 5. ICI power comparison of REC and ISP pulse

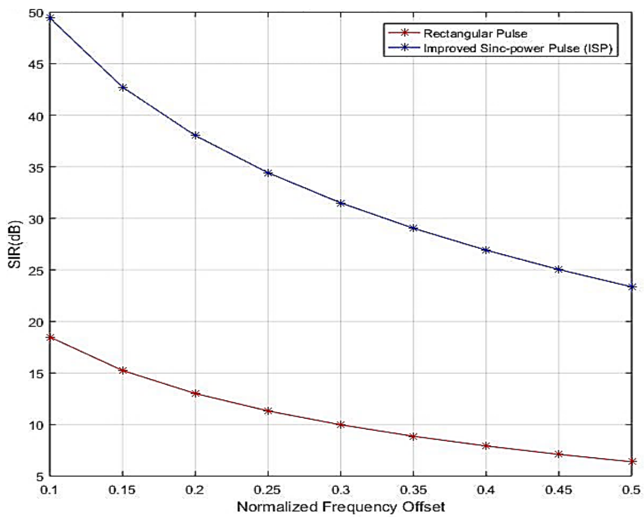

Figure 6. SIR performance comparison of REC and ISP pulse

4. CONCLUSION

In this paper, the implementation of pulse shaping techniques, REC and ISP pulse, have been introduced. REC and ISP pulse applied to OFDM system has been evaluated and compared to suppress the effect of ICI with the presence of CFO over fading channel. The ISP pulse performed better than REC pulse. It is due to that ISP pulse is able to minimize ICI power better than REC pulse. It also was able to produce higher SIR compared to REC pulse. So generally, by using pulse shaping, the performance of OFDM system seems to be better because of the implementation of pulse shaping reduces the side lobe power of a subcarrier which potentially cause ICI. Therefore, with the use of pulse shaping, a side lobe subcarrier will not interference to other subcarriers. The performance of OFDM system will degrade that effected by the presence of CFO, the higher frequency offset will increase ICI power.

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