International Research Journal of Engineering, IT & Scientific Research
Available online at https://sloap.org/journals/index.php/irjeis/
Vol. 9 No. 4, July 2023, pages: 111-120
ISSN: 2454-2261
https://doi.org/10.21744/irjeis.v9n4.2336

Performance Analysis of Pulse Shaping Rectangular Pulse through Frequency Selective Fading Transmission Channel in OFDM System

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Article history:

Submitted: 27 April 2023
Revised: 18 May 2023
Accepted: 09 June 2023

Keywords:

ICI;
LTE;
OFDM;
pulse;
rectangular;

Abstract

Long Term Evolution or LTE is a fourth-generation (4G) cellular network technology that uses OFDM as its multiplexing technique for fast and effective wireless communication services. OFDM uses the concept of orthogonality for bandwidth efficiency by multiplexing overlapping subcarriers. But in its implementation, this system will have problems in the transmission channel. In addition, OFDM has the major drawback of being susceptible to frequency offset between the transmitter and receiver. This offset frequency will cause the orthogonal character built in the OFDM system to experience a decrease in performance. This decrease in performance is due to the occurrence of ICI. To overcome this, a method is needed to improve system performance. The method used in this research is Rectangular Pulse. Therefore, this research is made to combine the advantages of OFDM and pulse shaping and is expected to produce a superior system that can contribute to the improvement of 4G-LTE implementation. The approach method in this research applies a quantitative descriptive approach to analyze system performance and in this research uses the simulation method as a reference to obtain research data using the Matlab application. The results obtained from this research are OFDM with pulse shaping rectangular pulse has better ICI reduction results because it is able to make the side lobe of each subcarrier look flat so that when ICI occurs there will be no interference between subcarriers.

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ISSN: 2454-2261

1 Introduction

One of the technologies used to create fast and effective wireless communication services is LTE (Long Term Evolution). For uplink and downlink, the LTE technology multiplexing technique used in 4G is Orthogonal Frequency Division Multiplexing (OFDM) (Wirastuti et al., 2020). OFDM is a multicarrier modulation method where the subcarriers are mutually orthogonal. Subcarriers can overlap without causing ISI (inter-symbol interference) effects due to their orthogonal nature. Naturally, OFDM can reduce bandwidth by multiplexing overlapping subcarriers (Yuniari et al., 2016). The procedure followed is identical to the multicarrier modulation method, with the only difference being the use of mutually orthogonal subcarriers in each subchannel. OFDM is widely used in wireless data transmission because OFDM has a fairly high data transmission rate and has a higher bandwidth efficiency compared to other types of multiplexing technologies (Kang et al., 2010).

The characteristic of wireless channels is the presence of multipath channels. The influence on this multipath channel causes fluctuations in the amplitude, phase and angle of arrival of the received signal. The communication path used can be a frequency-selective fading channel, where the channel bandwidth is narrower than the transmission bandwidth, resulting in non-uniform attenuation of the received power at certain frequencies.

In addition, OFDM has the major drawback of being susceptible to frequency offset between the transmitter and receiver. The effect of this frequency offset is that the orthogonal character of the subcarrier can be lost and can experience a frequency shift or what is called Intercarrier Interference (ICI) (Megasari et al., 2019). This frequency offset is caused by the Doppler effect and due to frequency mismatch in the sending and receiving oscillators. ICI will reduce system performance. Therefore, efforts are needed to reduce ICI in OFDM systems. The efficiency of the OFDM system will be affected by the presence of ICI. Therefore, demodulating the received data requires proper and effective ICI reduction. The pulse shaping technique is one of the many strategies suggested for ICI reduction.

With pulse shaping, the subcarriers in an OFDM system are filtered while still in an orthogonal state to each other, thus reducing interference from other subcarriers' sidelobes at the receiver. This is one way to address the main cause of ICI. Combining the advantages of OFDM and pulse shaping with a rectangular pulse is expected to produce a superior system. Combining the advantages of each system is expected to contribute to the improvement of 4G-LTE implementation with the OFDM system and its development in cellular networks as well as the implementation of 5G system in the future.

In previous research on this issue, the author only explained Improved Sinc Power Pulse (ISP) (Prayoga et al., 2019). In this research, the OFDM system will be combined with the Pulse Shaping technique, especially the rectangular pulse type in the Frequency Selective Fading channel, and will also simulate the performance of the OFDM system without pulse shaping. The best system can then be determined by comparing the performance of the two systems.

2 Materials and Methods

Research approach methods

This research applies a quantitative descriptive approach to analyze system performance. This approach refers to the theory and literature study of previous research. Finally, an analysis of the results of measurements and observations of the research is also carried out which will result in the performance of the system.

Research instruments

This research uses the simulation method as a reference to obtain research data. This instrument is used to design and run simulations. The instrument is divided into two types, hardware, namely a computer with Windows OS and software in the form of a Matlab program. In this study, the systems to be simulated include:

1) OFDM is a transmission technique that uses a multicarrier frequency. Each sub-carrier is orthogonal and harmonious with each other so that adjacent sub-carriers can overlap without causing ICI. OFDM spectrum efficiency is higher when compared to conventional modulation techniques such as Frequency Division Multiplexing (FDM) (Purwanto et al., 2015).

2) Pulse shaping aims to eliminate or minimize the side lobe amplitude of a subcarrier that has the potential to cause ICI so that ICI will be reduced and also be able to improve the performance of the OFDM system (Ashish & Prasad, 2017). Because in the OFDM spectrum, each subcarrier consists of a main lobe and many side lobes. When the orthogonality between subcarriers is reduced, the side lobes will potentially generate ICI power in the center area of each subcarrier. The ICI power will increase when the carrier offset frequency also increases. In this research, the Rectangular Pulse-type is used which is able to reduce the ICI power from the side lobe (Sucipto et al., 2020). The equation of the rectangular pulse is shown in equation (1) (Vaghela et al., 2016).

$$P_{rec}(\Delta f) = sinc(\Delta f T) \qquad (1)$$

3) Carrier Frequency Offset (CFO) or frequency offset is caused due to the Doppler effect or due to a frequency mismatch in the sending and receiving oscillators resulting in a loss of orthogonality (Utomo et al., 2015). This loss of orthogonality between subcarriers will cause ICI because the side lobe of a subcarrier will interfere with other subcarriers. CFO has a normalization value denoted by ε (Hidayat, 2016). The value of ε will show how much subcarrier shift is detected by the receiver oscillator (Jung & You, 2018). Where the value of $\varepsilon \leq 1$ and ε has the equation as in Equation (2) (Singhai & Gupta, 2016).

$$\varepsilon = \frac{f_{offset}}{\Delta f_c} \qquad (2)$$

Data collection methods

In this research, the data used is generated from Matlab software simulations. The simulation carried out has stages, namely making OFDM modeling coding scripts in frequency selective fading channels influenced by frequency offset. Then make OFDM modeling with the addition of a Rectangular pulse. The simulation model consists of randomly generating data bits, QPSK modulation, OFDM system, the addition of Rectangular pulse, the addition of frequency selective fading noise channel added with AWGN thermal noise. The BER value versus Eb/No will be calculated as the value of the system performance parameters. The simulation parameters of this research use the simulation parameters shown in Table 1.

This research has a process flow to carry out the research stages. The flow of research and simulation is carried out by adding a frequency offset parameter. From this addition, the effect of the offset frequency on system performance will be analyzed. After seeing the effect of the offset frequency, the pulse shaping reduction technique will be applied. In this research, two types of reduction techniques are used, namely Rectangular Pulse Shaping.

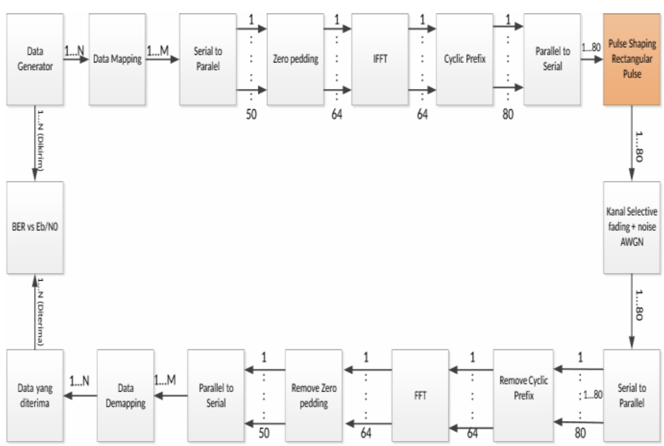

Figure 1. OFDM system modeling with rectangular pulse

Table 1
Simulation parameters

Parameters	*Value*
Number of subcarriers	64
Number of FFT symbols	64
Modulation type	QPSK
Zero Padding	14
Number of bits per OFDM	50
Cyclic prefix length	16
Eb/No range	-10 : 1 : 10
Number of Input bits	1.000.000 bit
Pulse shaping type	*Rectangular pulse*
Transmission Channel Type	AWGN + *Frequency selective fading*

Research flow

At the beginning of this research, researchers conducted literature studies from related journals, books, and other literature. Literature studies are carried out in order to get problems that can be used as research objects. The next stage is to create an OFDM model in the frequency-selective fading channel with the influence of frequency offset. Simulation models that will be made include random bit generation, QPSK modulation, OFDM process and running the Rectangular Pulse process through AWGN and frequency selective fading channels, and calculating BER and Eb/No values as system performance parameters.

In Figure 1, we can see the complete OFDM Block with Rectangular Pulse. Initially, on the transmitter side, the bits inputted from the generator will undergo a modulation process on the mapper using QPSK modulation so that the bits in the form of 1 to N bits will be converted into 1 to M (M = N / 2). In the next block, the data stream that was previously in series will be made parallel and added to Zero Padding in the Zero Padding block. In the IFFT block the symbol will be converted into samples according to the IFFT operation which is then added to the Cyclic Prefix. After adding Cyclic Prefix, the sample will be made into series again to add rectangular pulse and transmitted.

The receiving side is the opposite of the sending side. The received serial signal will be made parallel again, then the Cyclic Prefix is discarded and the data will go through the FFT process to get back the sent symbol. After that Zero Padding will be removed and will be converted back to serial form. Then the data will be demodulated to get the output data. Counting the amount of erroneous data at the receiver, also known as bit error rate (BER), is one technique to assess the performance of a communication system. BER is performed by comparing the transmitted and received data, which is then compared to the Eb/No (Energy Bits per Noise) ratio. For the final simulation, the author compares the OFMD system with the OFDM system using the rectangular pulse effect. The effect of the two systems is shown by comparing BER to Eb/No. The smaller the BER value, the better the system performance.

3 Results and Discussions

OFDM system simulation

The purpose of OFDM simulation is to evaluate the performance of the OFDM system using BER vs Eb/No parameter in frequency selective fading transmission channel. Figure 2 depicts a graph showing the performance of the OFDM system on AWGN and frequency selective fading channels. In Figure 2, it can be seen that the BER vs. Eb/No graph for OFDM systems on frequency selective fading transmission channels is worse than OFDM systems on AWGN transmission channels. In accordance with the BER value displayed in Table 2, when Eb/No is 10 dB, the BER value generated in the OFDM system on the frequency selective fading transmission channel is 0.070758 while the BER value generated in the OFDM system on the AWGN transmission channel is 0.021744. At Eb/No worth 10 dB, the BER value generated by OFDM on AWGN transmission lines has a difference of 69% from OFDM on frequency selective fading transmission lines (Sung et al., 2015; Steendam & Moeneclaey, 2000; Sarowa et al., 2018; Aisyah, 2015).

It can be seen from Figure 2 that the modeling in the frequency selective fading transmission channel which is described in cyan color has a greater BER value. This is because frequency selective fading channel modeling passes the transmitted data on a channel or communication channel that has a fading effect and adds the influence of AWGN noise in the transmission process between the sender and receiver.

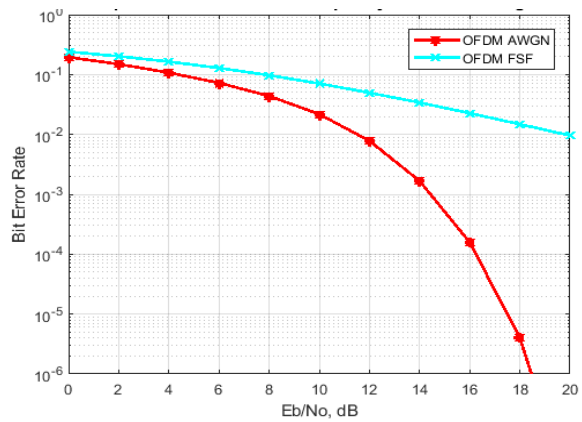

Figure 2. BER of OFDM on AWGN and frequency selective fading channel

Table 2
BER value for comparison of OFDM system in AWGN and frequency selective fading channel

Eb/No	*Bit Error Rate*	
	OFDM Kanal AWGN	*OFDM Kanal FSF*
0	0.194860	0.240754
2	0.148991	0.202117
4	0.107420	0.163998
6	0.072473	0.128451
8	0.043799	0.097175
10	0.021744	0.070758
12	0.007814	0.049614
14	0.001672	0.034036
16	0.000157	0.022615
18	0.000004	0.014795
20	0	0.009599

Simulation of rectangular pulse OFDM system

Following the modeling of the OFDM Rectangular pulse system in Figure 1, a simulation of the OFDM system with rectangular pulse shaping is performed. Based on BER vs. Eb/No parameter, this simulation aims to assess the performance of the OFDM system using a rectangular pulse on a frequency-selective fading transmission channel. Figure 3 displays the performance graph of the OFDM system with rectangular pulse shaping on AWGN and frequency-selective fading transmission channels (Zhao et al., 2019; Le, 2008; Fusco et al., 2008; Saxena & Joshi, 2013).

From Figure 3, it can be seen that the BER vs. Eb/No graph for the OFDM Rectangular pulse system on the frequency selective fading transmission channel is worse than the OFDM Rectangular pulse system on the AWGN channel. In accordance with the BER value displayed in Table 3, when Eb/No is 10 dB, the BER value generated in the OFDM Rectangular pulse system on the frequency selective fading transmission channel is 0.040126 while the BER value generated in the OFDM Rectangular pulse system on the AWGN transmission channel is 0. 003505. At

Eb/No worth 20 dB, the BER value generated by OFDM Rectangular pulse on the AWGN transmission channel has a difference of 91% from the OFDM Rectangular pulse on the frequency selective fading transmission channel.

From Figure 3, an Eb/No of 8 dB is required in the rectangular pulse OFDM system to obtain a BER of 10^{-2} over an AWGN transmission line. Meanwhile, an Eb/No of 16 dB is required on the transmission line for frequency selective fading.

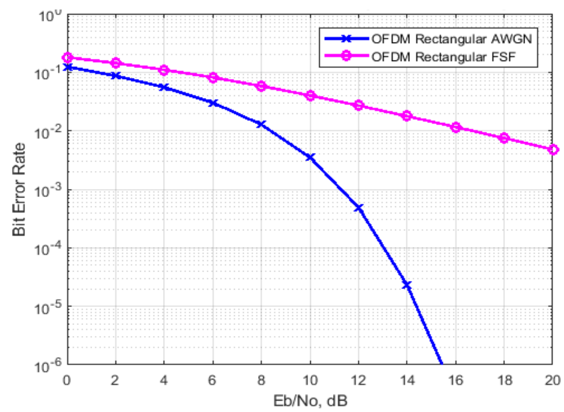

Figure 3. BER of OFDM rectangular pulse on AWGN and frequency selective channel

Table 3
BER values for comparison of OFDM Rectangular pulse system in AWGN and frequency selective channel

Eb/No	*Bit Error Rate*	
	OFDM REC Kanal AWGN	*OFDM REC Kanal FSF*
0	0. 124442	0.179986
2	0. 086598	0.143377
4	0. 055297	0.109977
6	0. 030257	0.081562
8	0. 012743	0.058094
10	0. 003505	0.040126
12	0. 000489	0.026944
14	0.000002	0.017752
16	0	0.011591
18	0	0.007479
20	0	0.004774

It can be seen from Figure 3 that the modeling in the frequency selective fading transmission channel which is described in magenta color has a higher BER value compared to the blue AWGN transmission channel, as shown in Figure 3. This is because in the Frequency Selective Fading transmission channel the data transmitted is not only through the communication channel or channel with fading effects but also through AWGN noise when transmitted between the sender and receiver.

Comparison of OFDM system with OFDM Rectangular pulse

From the two simulations that have been carried out in sections A and B, section C compares the simulation results for OFDM systems with OFDM Rectangular pulse based on BER vs. Eb/No parameters and frequency selective fading transmission channels shown in Figure 4. From Figure 4, it can be seen that the BER vs. Eb/No graph for OFDM systems without pulse shaping is worse than OFDM Rectangular pulse systems in frequency selective fading channels. In accordance with the BER value displayed in Table 4, when Eb/No is 20 dB, the BER value generated in the OFDM system without pulse shaping is 0.009599 while the BER value generated in the OFDM Rectangular pulse system is 0.004774. At Eb/No of 20 dB, the BER value generated by OFDM Rectangular pulse is reduced by

51% from OFDM without Pulse Shaping (Kamal et al., 2016; Kumbasar & Kucur, 2007; Doukas & Kalivas, 2010; Mask et al., 2019).

By analyzing the simulations that have been carried out regarding the application of pulse shaping in OFDM systems, especially rectangular pulse which is influenced by offset frequency, it can be concluded that the application of pulse shaping has a good impact on the performance of OFDM systems. This is because the interference effect of the subcarrier can be minimized by reducing the ICI power. ICI is caused by side lobe shift that causes interference on each subcarrier, the rectangular pulse is able to reduce the influence of the side lobe by making it look flat and minimizing ICI.

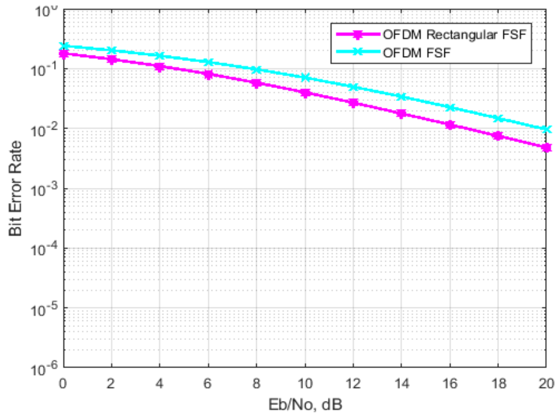

Figure 4. BER Comparison of OFDM rectangular pulse and OFDM without pulse shaping on frequency selective Fadin channel

Table 4
BER value for comparison of OFDM System den OFDM Rectangular pulse

Eb/No	*Bit Error Rate*	
	OFDM	*OFDM Rectangular*
0	0.240754	0.179986
2	0.202117	0.143377
4	0.163998	0.109977
6	0.128451	0.081562
8	0.097175	0.058094
10	0.070758	0.040126
12	0.049614	0.026944
14	0.034036	0.017752
16	0.022615	0.011591
18	0.014795	0.007479
20	0.009599	0.004774

4 Conclusion

Based on the simulation results and discussions that have been carried out, several conclusions are obtained, including the following:

1) The AWGN transmission channel has a lower BER value than the Frequency Selective Fading transmission channel in the OFDM system without pulse shaping. When Eb/No is 10 dB, the BER value generated in the OFDM system on the frequency selective fading transmission channel is 0.070758 while the BER value generated in the OFDM system on the AWGN transmission channel is 0.021744.

2) AWGN transmission channel has a lower BER value than Frequency Selective Fading transmission channel in the performance of OFDM system with Rectangular pulse shaping. When Eb/No is 10 dB, the BER value generated in the OFDM Rectangular pulse system on the frequency selective fading transmission channel is 0.040126 while the BER value generated in the OFDM Rectangular pulse system on the AWGN transmission channel is 0. 003505.

It was found that the performance of the OFDM system with Rectangular pulse shaping is superior when the performance of the OFDM system without pulse shaping is compared. Eb/No is 20 dB, the BER value generated in the OFDM system without pulse shaping is 0.009599 while the BER value generated in the OFDM Rectangular pulse system is 0.004774. At Eb/No worth 20 dB, the BER value generated by OFDM Rectangular pulse is reduced by 51% from OFDM without Pulse Shaping.

Conflict of interest statement
The author declared that he has no competing interests.

Statement of authorship
The author has a responsibility for the conception and design of the study. The author has approved the final article.

Acknowledgments
I am grateful to two anonymous reviewers for their valuable comments on the earlier version of this paper.

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