OFDM Simulation Using GNURadio on Dynamic Channels

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Abstract. OFDM system can be implemented on GNU Radio, one type of SDR (software-defined radio). SDR is a transmitter and receiver system that uses digital signal processing to code, decode, and modulate data. GNU Radio is used as a transmitter and receiver model for quality measurements for the working of the OFDM system under various conditions. This measurement will compare real-time data transmission performance results through AWGN channels and dynamic channel models, namely Rayleigh Distributed (NLOS) and Rician (LOS). The specification of the OFDM system used in this study is to use GNU Radio software with BPSK modulation (Binary Phase Shift Keying). The simulation model's output in the GRC during real-time data transmission via AWGN and Rayleigh distributed (NLOS) and Rician Distributed (LOS) model channels with GNU Radio is the performance of OFDM signals with the noise of 25mV, 50mV, 100 mV, and 200mV. The results of the research simulation obtained SNR values on AWGN, NLOS, and LOS channels directly proportional to *noise*. The SNR value is down significantly to four times the initial value.

Keywords: GNURadio · Digital Communications · OFDM · Dynamic Channels

1 Introduction

With the development of communication technology, the demand for more extensive/faster data rates services such as multimedia, voice, and data via cable and wireless is also increasing [1, 2]. To achieve a more significant data rate, of course, requires bandwidth in a single carrier transmission because the minimum bandwidth needed is equal to Rs/2 (Hz), where Rs is the symbol rate. When the signal bandwidth becomes more significant than the coherent bandwidth on a wireless channel, it is subject to multipath fading resulting in Inter-Symbol Interference (ISI) [3]. In general, adaptive equalizers are developed to address ISI due to multipath fading channels [4]. But the more data rates increase, the more difficult the compensation is designed to be complicated to implement.

To solve this problem, the right solution for high data rates is to use multicarrier transmission. Because on multicarrier transmissions, the total bandwidth available in the spectrum is divided into subbands for multicarrier transmissions in parallel form.

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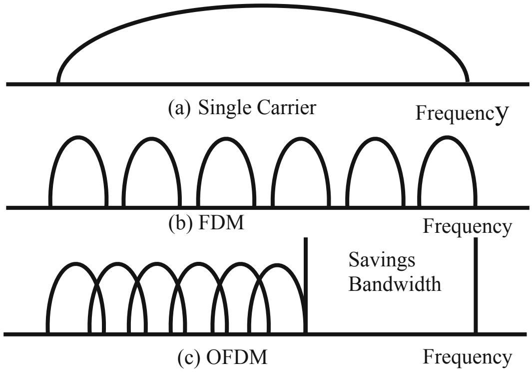

Fig. 1. Comparison of Single Carrier, FDM, and OFDM

The bandwidth for each sub-band is relatively smaller compared to coherent bandwidth. For example, multicarrier transmission is OFDM, wherein this OFDM allows the carriers to have a narrow distance even to overlapping each other so that it is more bandwidth-efficient when compared to other multicarrier such as Frequency Division Multiplexing (FDM) [3, 5]. OFDM itself has been applied to various telecommunication system standards in both wireless and wireline technology as an example of IEEE802.1z1g for wireless LANs (Wifi) standards. Here is a comparison image of signals on a single carrier, FDM, and OFDM (Fig. 1).

In this paper, the process of implementing and evaluating the performance of OFDM on dynamic channels uses SISO (Single Input Single-Output) communication [2] so that it only uses simulations from software. Such communication can be implemented on an SDR (Software Defined Radio), namely GNU Radio. GNU Radio is a type of wireless open-source communication system software that will be implemented for OFDM techniques with various measurement conditions.

2 Theoretical Foundation

2.1 AWGN Channel

Additive White Gaussian Noise (AWGN) is an additive channel due to the increase in noise to send signals and cannot be doubled. The noise in this channel will be randomly significant under normal circumstances. Therefore, it cannot determine the amount of noise. Otherwise, rejecting the exact amount of noise will get the receiver without any sound, meaning white, because each frequency's power is equal [6]. Therefore, at each frequency, the noise level and frequency domain are fixed. On channel A, Gaussian noise is allowed in the current cause. Noise is defined through the front. It has a spectral intensity of energy. The channel AWGN is the perfect pattern for satellite communication. It is not ideal for links obtained due to overlapping, plentiful, relief cover, etc. Considering bandlimited Gaussian channels that operate in additional Gaussian noise, the Shannon-Hartley Theorem can be used, which states that channel capacity was formulated with [7, 8].

$$C = Blog_2 + \left(1 + \frac{S}{N}\right) \tag{1}$$

where C is the capacity in bits per second, B is the channel's bandwidth in Hertz, and S = N is the Signal to Noise Ratio.

2.2 Rayleigh Fading Channel Model (NLOS)

In regular vehicle traffic, buildings, and other objects, signals come at receivers and senders in different lanes. When there are different signal paths between receivers and transmitters, Rayleigh limits the motion entirely to the receiver and can change the probability of the intensity of the Rayleigh Fading channel function [9] and can be expressed in the equation [10, 11].

$$p(r) = \frac{r}{\sigma^2} exp\left[-\frac{r^2}{2\sigma^2}\right] forr \geq 0 \tag{2}$$

where σ^2= the difference from random variable r = amplitude of the signal receiver

$$h(t) = \sum_{n=1}^{N} a_n e^{j(2\pi f_n t + \varphi_n)} \tag{3}$$

where N is the number of multipath and a_n is the amplitude of the n^{th}.f_n path, φ_n is representing the shift in Doppler frequency and phase of each path. n^{th} The Doppler frequency of the shift expres $f_n = (v/c)f_c cos\theta_n$ as, where is the v speed of motion of the user. c It is the speed of light, f_c is the carrier of frequency and is the angle between the θ_n User's movement direction and the angle of the radio wave coming.

2.3 Rician (LOS)

The receiver signal is a mixture of multipath fading and the visible trajectory between the receiver and sender. The LOS line (line of sight) is a signal path that exits directly from the sender to the receiver. The action of rayleigh fading on the sending signal will be more than Rician Fading. The probability intensity of a fading rician channel function can be expressed in the equation [10, 12].

$$p(r) = \frac{r}{\sigma^2} exp^{\left(\frac{-(r^2+s^2)}{2\sigma^2}\right)} I_0\left(\frac{rs}{\sigma^2}\right) forr \geq 0, s \geq 0 \tag{4}$$

LOS (line of sight) is an assumed condition for propagation of a trajectory with a positive free distance or no obstruction whatsoever. The distribution of LOS. It mainly depends on the location of the base station antenna and the line of *sight* area open around the site [13]. LOS identified three similar cases:

- With a circular area available around the *base station,*
- Half the LOS open space when the base station antenna is mounted on the roof at the edge of the building block.
- The LA/NLOS status distribution is homogeneous throughout the base station coverage area without a LOS area close to the base station.

In the case of the Rician distribution, the transmitted signal experiences non-fading dominance due to the presence of a Line of Sight (LOS) line between the transceiver, so it is assumed there is no obstruction. In this context, many weaker random multipath signals arriving at different angles are generated by reflection, diffraction, or scattering effects superimposed on the dominant signal. This ratio between deterministic signal strength and variance of the multipath is known as Rician.

The study measured the value of Signal Noise to Ratio (SNR) using GNU Radio on Modulation of Orthogonal Frequency Division Multiplexing (OFDM). The signal-to-noise ratio was defined as the ratio between the desired power and noise power signal and is comprehensive to be used as a standard measure of signal quality for communication systems. An information signal as a communication medium will experience a lot of interference by noise to damage the information signal. Signals that share this disruption experience a decrease in quality. The quality of this signal can be determined from the Signal value to the Noise Ratio (SNR) measured in decibels (dB) [14]. Signal to noise ratio calculations can be done through a reduction between noise value and frequency strength [15].

3 Design

The block diagram as a whole is shown in Fig. 2. The explanation is as follows: Random bits are generated, then modulated BPSK (Binary Phase Shift Keying). In BPSK modulation, two possible phase outputs will come out and carry information (Binary, i.e., 2). One output (0°) represents a logic one and the other (i.e., 180°) logic 0. By the changing state of the digital input signal, the phase at the carrier's output shifts between two angles that are both 180° (out of phase) apart. Figure 2 shows the configuration of the design and measurement of the channel. On a single SDR or GNU Radio worksheet, transceiver blocks are assembled as digital signal processing. These transceiver blocks are created to be able to transmit signals multicarrier. The signal is not emitted with a GNU Radio simulation, so it does not require an antenna and RTL. The signal will be sent and directly received by the receiver block, and the PC processes the information signal as the sending and receiving system. The data received will be taken from FFT output, phase, and magnitude for SNR measurements.

Then the serial signal is converted to a parallel signal form. Then each similar signal goes into the IFFT block. Multicarrier is signal coming out from the IFFT block. The

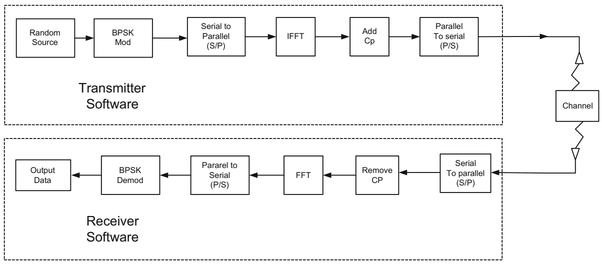

Fig. 2. Design Diagram Block

multicarrier signal is added CP to reduce ISI. Before it is sent, the parallel OFDM signal is converted to a serial OFDM signal form. After passing through the channel, the OFDM signal is converted back to a parallel signal form. The CP will be discarded on the receiving side, and then the multicarrier signal goes into the FFT block. In FFT blocks, the multicarrier signal is converted into a parallel subcarrier signal [16, 17]. The information subcarrier signal will go into the P/S block, then modulates to get the information bits back.

The IFFT (Inverse Fast Fourier Transform) and FFT (Fast Fourier Transform) algorithms serve as modulators and demodulators on OFDM. The image can be explained binary data mapped in the BPSK mapper will produce a mapper result symbol. The symbol is broken down in serial to parallel form and modulated by a subcarrier signal with a specific frequency, resulting in interlocking orthogonal signals. Then all the signals are added so that the OFDM signal is generated.

$$s(t) = \sum_{k=0}^{k-1} s(k)sin\left(\frac{2\pi tk}{k}\right) + j\sum_{k=0}^{k-1} s(k)cos\left(\frac{2\pi t^k}{k}\right) \tag{5}$$

With:
K = Number of IFFT points (total subcarrier).
s(t) = signal value in the time domain.
s(k) = the value of the kth spectrum (frequency domain).

The demodulator OFDM used the Fast Fourier Transform (FFT) algorithm to parse the SYMBOL OFDM. The symbol is changed from a time domain to a frequency domain in the FFT algorithm, as shown in the equation.

$$s(k) = \sum_{k=0}^{k-1} s(t)sin\left(\frac{2\pi tk}{k}\right) - j\sum_{k=0}^{k-1} s(t)cos\left(\frac{2\pi t^k}{k}\right) \tag{6}$$

With:
K = Number of FFT points (total subcarriers).
s(t) = Signal value in the time domain.
s(k) = The value of the kth spectrum (frequency domain).

As explained earlier that the orthogonality of the OFDM symbol can be maintained by applying FFT on the receiver side. This can be achieved if there is no Intersymbol Interference (ISI) [18] and Intercarrier Interference (ICI) caused by transmission channels. However, this is very difficult to achieve because wireless transmission channels can generally cause a plural trajectory on the transmitted signal. This results in the receipt of the original signal that is delayed on the receiver. This symbol may interfere with the next symbol or interstitial from the previous symbol.

A way to overcome ISI by multipath channels is to insert guard intervals on each OFDM symbol. Guard intervals can be CP (cyclic prefix). In the OFDM system, CP plays an essential role in maintaining the orthogonality of the OFDM subcarrier in frequency-selective channel situations. CP is a series of bits formed by re-copying some of the bits of an OFDM signal. With this additional CP, the OFDM signal will not experience ISI as long as the channel spread delay is shorter than the duration of CP.

4 GNU Radio Simulation

This simulation uses GNU Radio type 3.7.11.1. This type has many blocks, such as input/source, sinks, and graphical sinks to misc. Random Source, OFDM Mod, WX GUI FFT sink, and other are blocks that are used in the simulation. Here are the blocks and their more complete functions in Table 1 (Figs. 3, 4, and 5).

After understanding the function per block, string together and configure each block with AWGN, NLOS, and LOS channels. Here is the documentation of the design block image on each channel (Table 2).

These simulations as a whole using BPSK modulation with the following parameters.

The image below is the result of simulations on each channel on both transmitters and receivers. The parameter used in this study is sample rate 500K after the parameters have been configured, then run the program on GNU Radio.

Table 1. Block parameters Simulation of AWGN, NLOS, and LOS channel

No	**Block**	Value
1	Random Source	Randomly generated sample numbers
2	Short to Float	The flow short type converter becomes afloat.
3	OFDM Mod	Select modulation (BPSK, QPSK, 8PSK to QAM256)
4	Random source max	Set sample rates when there is no SDR (hardware)
5	Random source min	1. Media between transmit and receive blocks 2. Set noise voltage, frequency offset, and others
6	WX GUI FFT Sink	Monitor signals such as oscilloscope
7	OFDM Demod	Modulating carrier signals
8	Float to Short	Flow float type converter becomes short
9	File Sink	Save information signals with specific directories

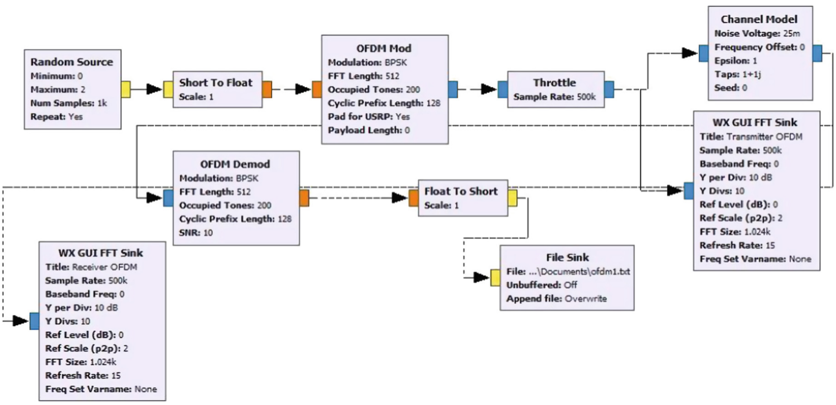

Fig. 3. OFDM *Transceiver* Block on AWGN channel

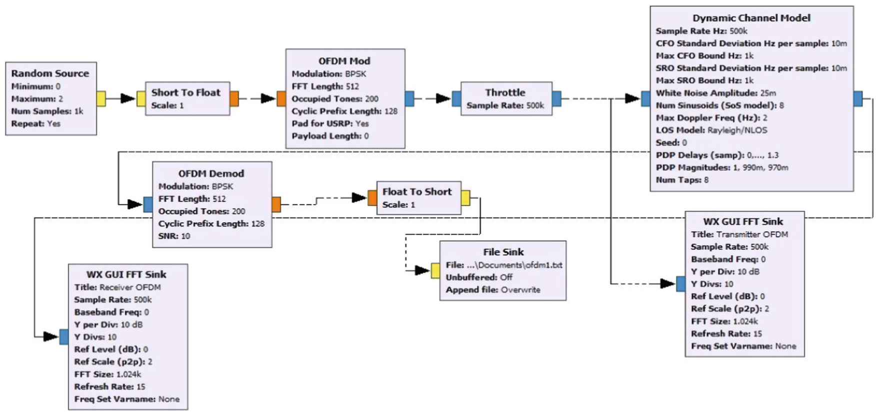

Fig. 4. OFDM *Transceiver* Block on NLOS channel

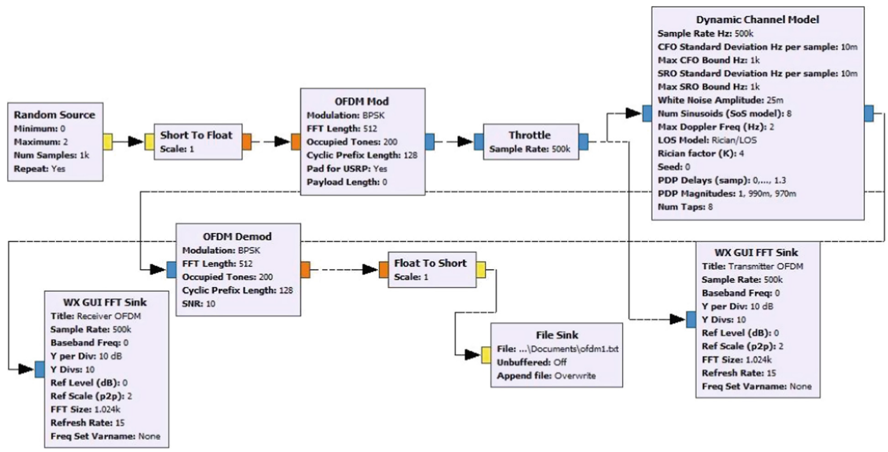

Fig. 5. OFDM *Transceiver* block on LOS channel

Table 2. Block parameters Simulation of AWGN, NLOS, and LOS channel

No	Block Parameters	Value
1	FET Length	512
2	Sample rate	500 k
3	Modulation	BPSK
4	Random source max	2
5	Random source min	0

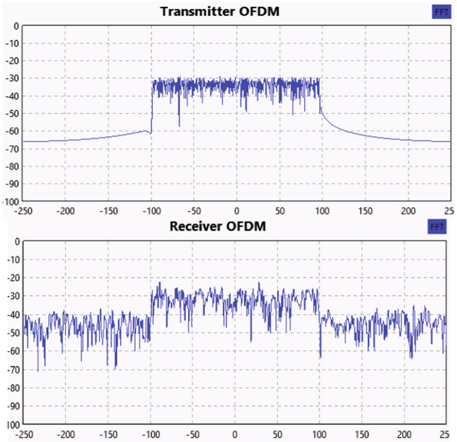

Fig. 6. Power and Noise Measurements on AWGN channels

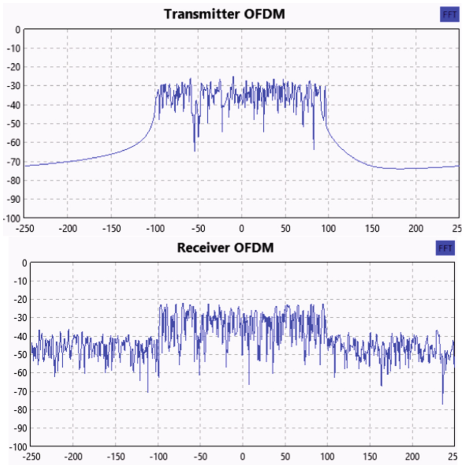

Fig. 7. Power and Noise Measurements on NLOS channels

The first simulation is that Fig. 6 is the result of power and noise measurements for SNR measurements on AWGN channels, Fig. 7 measures on NLOS channels, and Fig. 8 is the result of measures on THE LOS channel. The authors took one sample from each channel from the three images above on a 100 mV noise test.

5 Analysis and Measurement Results

The results of these measurements aim to analyze the performance of OFDM in various conditions. The parameters used can be seen in subheading 4. This test is carried out in several ethics, namely by changing the noise size on AWGN, NLOS, and LOS channels. In SNR measurements, the parameters measured are by changing the noise voltage,

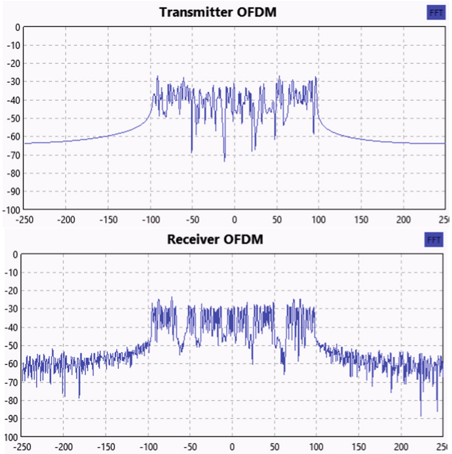

Fig. 8. Power and Noise Measurements on LOS channels

which is 25mV, 50 mV, 100 mV, 200 mV, and 500 mV. Here is an image of the signal output from the tests in this study.

In Table 3 shows the results obtained from the signal picture in FFT 512. It can conclude that the value of SNR produced is large when the noise is small. It means the greater the noise, the lower the SNR value, and the signal sent is harder to detect. In the category index of SNR i.e., 29.0 dB ~ and above: very good, 20.0 dB–28.9 dB: good, 11.0 dB–19.9 dB: enough. The SNR value obtained from research on the transmitter side is constant at 30 dB, which means very good. While on the AWGN channel receiver obtained SNR values of 20 dB at noise 25mV and 50 mV, which means good, SNR 10 dB at noise 100 mV and 200 mV, which means less good.

Furthermore, on the NLOS channel, the value of SNR 30 dB with 25 mV noise is categorized as very good, 20 dB with 50 mV noise is categorizing as good, 15 dB with 100 mV noise is categorized as sufficient, and 10 dB with 200 mV noise in the category is not good. Lastly, for the LOS channel on the receiver, obtained SNR value of 20 dB with the noise of 25 mV and 50 mV categorized as good, 15 dB with the noise of 100 mV falls into the category of enough and 10 dB with noise 200 mV category is not good. From the results of SNR measurements in this study, the highest SNR is in NLOS, which is 30 dB with 25 mV noise which falls into the category of very good, so it does not have a big effect on the signal. Furthermore, the lowest SNR is 10 dB, with the most extensive noise of 200 mV on the receiver side on all channels. This 10 dB SNR dramatically affects the information signal, as high noise power almost reaches the information signal power itself.

In Table 3 shows the results of SNR values on AWGN, NLOS, and LOS channels. It shows differences in OFDM modulation phases it's caused. In the image displayed, the performance results that deliver on in a while.

Table 3. SNR Value Measurement Results

No	**Noise**	Transmitter			Receiver		
		AWGN	NLOS	LOS	AWGN	NLOS	LOS
1	25 mV	30 dB	30 dB	30 dB	20 dB	30 dB	20 dB
2	50 mV	30 dB	30 dB	30 dB	20dB	20dB	20 dB
3	100 mV	30 dB	30 dB	30 dB	10 dB	15 dB	15 dB
4	200 mV	30 dB	30 dB	30 dB	10 dB	10 dB	10 dB

6 Conclusion

The results of simulations that we have done on AWGN, NLOS, and LOS channels concluded that the value of SNR is directly proportional to noise. The higher the noise, the lower the SNR. The decrease in SNR occurred significantly when the final noise raised four times the initial noise.

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