 ISBN : 978-602-0917-14-6

Implementation of Digital Modulation with Single Carrier and Multi Carrier OFDM Schemes Using USRP

Hendy Briantoro, I Gede Puja Astawa, Amang Sudarsono
Politeknik Elektronika Negeri Surabaya
hendy@pens.ac.id, puja@pens.ac.id, amang@pens.ac.id

Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier efficiency bandwidth scheme for digital communication where the frequency of OFDM subcarrier overlaps one another so that the spectrum is efficient. This research implements digital modulation BPSK, 4QAM and 16QAMin single carier and OFDM scheme using Universal Software Peripheral Radio (USRP). OFDM scheme hasbetter throughput than single carrier scheme, up to 90,789 MBps. By increasing the modulation type, the throughput also increases. In OFDM scheme, there are errors between experiment and calculation. Error of BPSK modulation is 2%. Error of 4QAM modulation is 2,17%. And error of 16QAM modulation is 2,95%. LOS condition has better throughput in up to 2 kBps than in obstacle condition.

Keywords: OFDM, USRP, BPSK, 4QAM, 16QAM

1. Introduction

High data rate transmission and efficiency data are required in wireless communication. One of the key to solve this problem is to use Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a multicarrier efficiency bandwidth scheme for digital communication where the frequency of OFDM subcarrier overlaps the other so that the spectrum is efficient[1]. There have been many researches regarding OFDM whether it is simulation using software or implementation in Field Programmable Gate Array (FPGA). For example, there was a research in Universidade de Aveiro about the implementation of OFDM at FPGA. Here, the receiver used the synchronization of Maximum Likelihood (ML) and Carrier Frequency Offset (CFO) Estimator to decrease the surplus information in the Cyclic Prefix (CP In addition, the channel equalization used Zero Forcing scheme while the channel estimation used Least Square. However, this research only implemented Xilinx System Generator in MATLAB using one FPGA. The process of sending and receiving data was not done for real from one device to another device but only inside one device, that was FPGA Virtex 6[2].

Nowadays, technology has already been developed rapidly. One of them is Software Define Radio (SDR) where the hardware is permanent but the software can be modified This can increase the flexibility in wireless technology and the effectiveness in using the hardware. One of the hardware which can support the implementation of Software Define Radio (SDR) is Universal Software Peripheral Radio (USRP). The main tool in URSP is Field Programmable Logic Array (FPGA) which can be programmed repeatedly [3].

There has been some research related to communication technology using USRP. One of them is about data transmission by several modulations, such as DPSK, DQPSK, and GMSK using USRP. These data transmission use Single Input Single Output (SISO) system. Furthermore Software Define Radio (SDR) is used to implement that system [4]. In addition, there was aresearch that had been conducted by Abirami M, Gandhiraj R, Soman K P on analyzing the performance of OFDM using GNU Radio and USRP in real time. Here, they use two methods, OFDM simulation was applied in GNU Radio software and OFDM was applied in real time. Here, the implementation of OFDM systems uses SISO (Single Input Single Output)[5].

Based on the previous researches, this research uses single carrier and multi carrier OFDM scheme using BPSK, 4QAM and 16QAM modulation which are implemented at USRP hardware. This research also measures throughput between the data sent and data received.

2. Related Works

There have been many researches concerning the communication technology using USRP. One of them was a research done by Ahmad Zainudin, Amang Sudarsono and I Gede Puja Astawa. The research was about data transmission with several types of modulation, such as DPSK, DQPSK, and GMSK using USRP. This data transmission uses Single Input Single Output (SISO). Software Define Radio (SDR) was used to implement that system[4]. Other research that has been done by Abirami M, Gandhiraj R, Soman K P to analyze the performance of OFDM using GNU Radio and USRP in real time. This research was conducted by using two methods, namely OFDM simulation applied on the GNU Radio and OFDM was practically

ISBN : 978-602-0917-14-6

implemented. And the digital modulations used were BPSK, QPSK, 8PSK, 16QAM, 64QAM, 256QAM. Moreover, the implementation of OFDM systems used SISO (Single Input Single Output) using a transmiter antenna and a receiver antenna [5].

In one of the university in Malaysia, Universiti Teknologi Malaysia, there is also a research regarding to the implementation of OFDM using QPSK and BPSK modulations in URSP. Here, the researcher examined about the value of Packet Received Ratio (PRR). For BPSK modulation and 512 FFT, the value of PPR ranged 98% to 100% for minimum DAC value 1000. For BPSK modulation and 256 FFT, the value of minimum PPR 98% for minimum DAC value 2000. For QPSK modulation and 512 FFT, the value of minimum PPR 98% for minimum DAC value 2000. And for BPSK modulation and 256 FFT, the value of minimum PPR 98% for minimum DAC value 3000 [6].

In University of Innsbruck Austria there was a research about the implementation of OFDM in URSP as well. Here, the receivers used were maximum likelihood estimation and pseudonoise (PN) sequence correlation. Besides, the receiver also comprised both the physical layer as well as the complete decoding process including the MAC layer of IEEE 802.11a/g/p networks. The modulation which is used is BSK and QPSK [7].

3. Theory

Orthogonal Frequency Division Multiplexing (OFDM) is a wireless communication technology that is popular today. OFDM has been adopted in wireless standards such as the Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB-T), IEEE802.11 a standard for Local Area Network (LAN), and the IEEE802.16 a standard for metropolitan area networks (MAN) [3]. OFDM is a multicarrier efficiency bandwidth scheme for digital communication where the frequency of OFDM subcarrier overlaps the other so that the spectrum is efficient [8].

OFDM is a wireless technology that uses a dividing technique to divide carrier into several subcarriers which are orthogonal one another. Multiple orthogonal subcarrier signals overlap in the spectrum can be generated by generalizing the single carrier Nyquist criterion into a multi-carrier criteria on. Practically, the process of the Discrete Fourier Transform (DFT) and inverse DFT (IDFT) is useful for the implementation of orthogonal signals. DFT and IDFT are efficient when the Fast Fourier Transform (FFT) and Inverse FFT (IFFT) are used. With the overlapping frequency therefore OFDM scheme can save the use of frequency. In OFDM scheme, there is a guard interval in the time domain which is called cyclic prefix (CP). This CP can reduce the inter-symbol interferences (ISI) between OFDM symbol[9]. Figure 1 shows block diagram of the transmitter and receiver in an OFDM system.

IFFT and FFT processes are the core in OFDM. IFFT is a modulator and FFT is a demodulator. FFT and IFFT equation can be written in equation (1) and (2).

FFT:

$$x(k) = \sum_{n=0}^{N-1} x(n) \sin\left(\frac{2\pi kn}{N}\right) + j\sum_{n=0}^{N-1} x(n) \cos\left(\frac{2\pi kn}{N}\right) \quad (1)$$

IFFT :

$$x(n) = \sum_{n=0}^{N-1} x(k) \sin\left(\frac{2\pi kn}{N}\right) + j\sum_{n=0}^{N-1} x(k) \cos\left(\frac{2\pi kn}{N}\right) \quad (2)$$

The following explanation is about the way how OFDM works. Data sent are converted into parallel, consequently if bit rate is R, then bit rate in every parallel channel is R/M where M is the number of parallel channel (the same as the number of subcarrier). After that, the modulation is performed on each sub-carrier. This modulation can be BPSK, QPSK, QAM or another. Then the modulated signal is applied to the Inverse Discrete Fourier Transform (IDFT), to generate OFDM symbols. This allows the use of IDFT frequency allocation orthogonal one another. After the OFDM symbols are converted into serial, then the signal is transmitted[10]. OFDM signal can be seen in Figure 1.

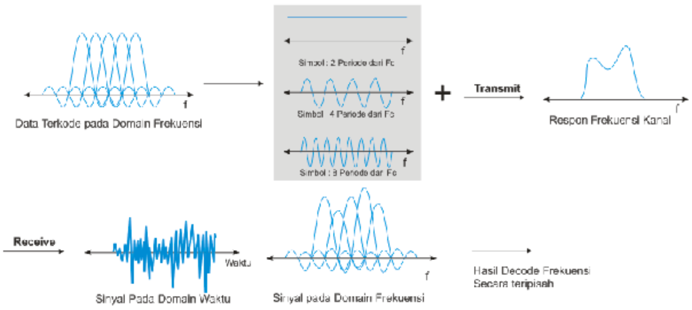

Figure1. OFDM Signal

OFDM signal x(t) in interval $mT_u \leq t \leq (m+1)T_u$ can be presented with equation (3).

$$x(t) = \sum_{k=0}^{N_c-1} x_k(t) = \sum_{k=0}^{N_c-1} a_k^{(m)} e^{j2\pi k\Delta ft} \quad (3)$$

With x(t): subcarrier which is k modulatedwith frequency $f_k = k.\Delta f$and $a_k^{(m)}$is the symbol of modulation applied in subcarrier during the m OFDM interval. The symbols of modulation can be BPSK, QPSK, 16QAM or 64QAM[11]. Two orthogonal subcarriers OFDM $x_{k1}(t)$ and $x_{k2}(t)$ are presented in equation(4).

$$\int_{mT_u}^{(m+1)T_u} x_{k1}(t)\, x_{k2}^{*}(t)\, dt = 0 \text{for } k_1 \neq k_2 \quad (4)$$

This research uses Universal Software Peripheral Radio (USRP) which has FPGA for processor, 100 MS/s dual ADC, 400 MS/s dual DAC and Gigabit

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Ethernet to communicate with personal computer. Physical NI USRP-2920 is shown in Figure 2.

Figure 2. NI USRP-2920
Source : http://sine.ni.com/ds/app/doc/p/id/ds-355/lang/en

4. Implementation

The "Implementation Digital Modulation With Single Carrier and OFDM Scheme Using USRP" research uses two NI USRP-2920, a personal computer, a switch time capsule. Figure 3 shows the block diagram transmitter and receiver in single carier scheme. Figure 4 shows a diagram transmitter and a receiver in OFDM scheme.This experiment uses LabView Software to implement block diagram in Figure 3 and 4. Figure 5 shows the configuration hardware this research. There are some parameters in this research.

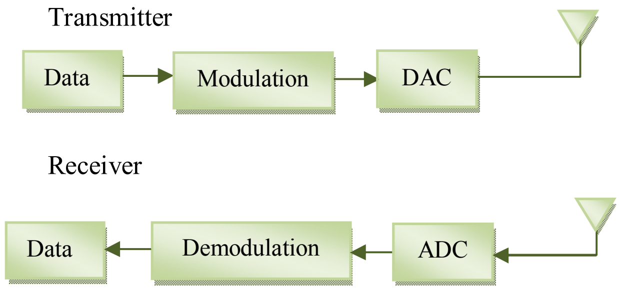

Figure 3. Block diagram oftransmitter and receiver in single carier scheme

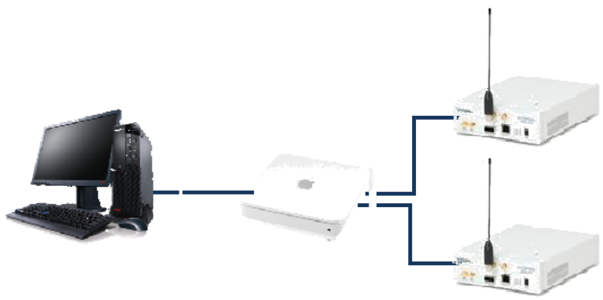

Figure 5. Hardware configuration

There are some parameters in this research. Table 1 shows this parameters. The experiments are done in laboratory with size 8 m x 8 m and there are two active access points inside the laboratory and 1 access point outside laboratory. The distance between 2 USRP is 500 cm.

Table 1. Parameters in experimental

	Single Carier	OFDM
Digital Modulation	BPSK, 4QAM and 16QAM	BPSK, 4QAM and 16QAM
Data	Streaming bit	Streaming bit
Frequency Carier	900MHz	900MHz
FFT size	-	64
1 Frame Data	-	256 bit
Cyclic Prefix	-	64 bit
Data of symbol OFDM	-	192

5. Experiment Result

The experiment transmit streaming bit using BPSK, 4QAM, and 16QAM modulation in single carrier scheme and OFDM scheme. Moreover, it uses various FFT size on OFDM scheme, measurement of throughput, and shows constellation diagram.

The first experiment measures the throughput of transmission streaming bits data using BPSK, 4QAM and 16QAM modulation with a single carrier scheme. A transmitter and a receiver are in Line of Sight (LOS) condition. The result shows in Figure 6. 16QAM modulation obtains throughput 664 kBps better than 4QAM modulation, and 1075 kBps better than BPSK modulation. The constellation diagram of BPSK, 4QAM and 16QAM is displayed in Figure 7, 8, and 9.

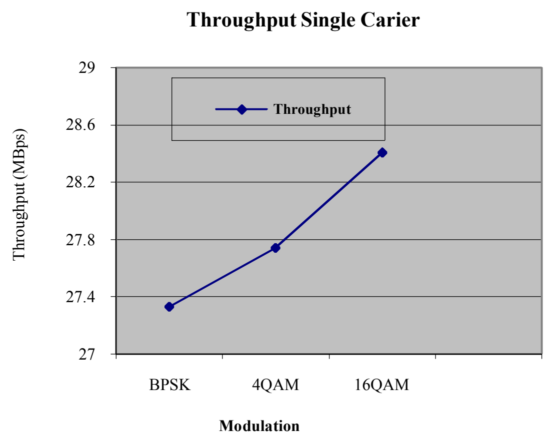

Figure 6. Throughput BPSK, 4QAMand16QAMmodulation with single carrier scheme

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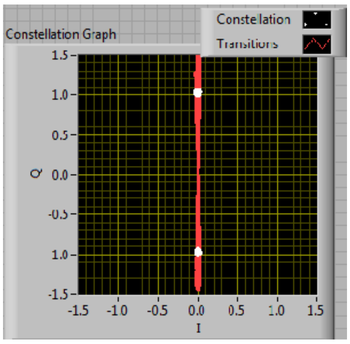

Figure 7. Constellation diagram of BPSK modulation

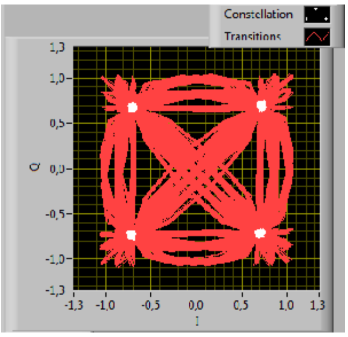

Figure 8. Constellation diagram of 4QAM modulation

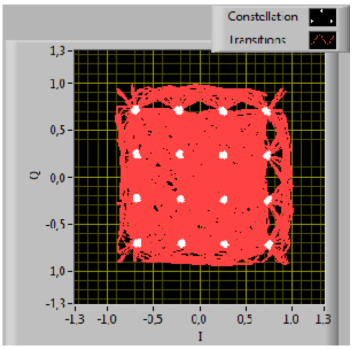

Figure 9. Constellation diagram of 16QAM modulation

Based on Figure 7, 8 and 9, it is seen that the constellation diagram is great. Digital modulation can work well. Data can be transmitted and received well.

The second experiment (LOS condition) measures the throughput of transmission streaming bits data using BPSK, 4QAM and 16QAM modulation with OFDM scheme. The transmitter and receiver are in Line of Sight (LOS) condition. Here, 1 frame data is 256 bit, FFT size is 64, cyclic prefix is 64 bit and data of OFDM symbol is 192. The result is shown in Figure 10. Throughput of OFDM with BPSK modulation is 30,087 MBps. Throughput of OFDM with 4QAM modulation is 60,270 MBps. Throughput of OFDM with 16QAM modulation is 119,189 MBps.

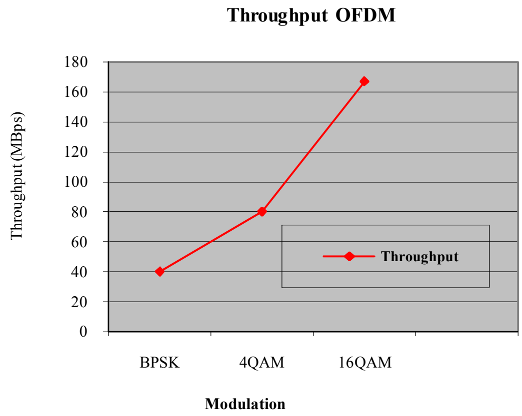

Figure 10. Throughput BPSK, 4QAM and 16QAM modulation with OFDM scheme

Theoritically, throughput can be found using equation (5).

$$Throughput = \frac{N}{T} = \frac{D \; x \; m \; x \; r}{T} \qquad (5)$$

Where:
N = Number of uncoded bits per OFDM symbol
T = OFDM symbol duration (in this experiment uses standard LTE, T = 4,69 µs)
D = Data of symbol OFDM (in this experiment, D= 192)
m = Bit of modulation (for BPSK, m = 1; for 4QAM, m= 2; for 16QAM, m = 4)
r = ratio of OFDM (in this experiment, r = ¾)

Throughput of OFDM with BPSK modulation in calculation is 30,703 MBps. Throughput of OFDM with 4QAM modulation in calculation is 61,607 MBps. Throughput of OFDM with 16QAM modulation in calculation is 122,814 MBps. In OFDM scheme, there are errors between experiment and calculation. Errors of BPSK modulation is 2%. Errors of 4QAM modulation is 2,17%. Errors of 16QAM modulation is 2,95%.

The 16QAM modulation with OFDM scheme has throughput 90,789 MBps better than single carier scheme. The 4QAM modulation with OFDM scheme has throughput 32,57 MBps better than single carier scheme. And BPSK modulation with OFDM scheme has throughput 2,787 MBps better than single carier scheme.

The third experiment (Obstacle 1 condition) measures the throughput of transmission streaming bits data OFDM scheme using BPSK, 4QAM and 16QAM modulation. The transmitter and receiver are placed in different room with distance 5m but the door between room is open. In this experiment, 1 frame data is 256 bit, FFT size is 64, cyclic prefix is 64 bit and data of OFDM symbol is 192. The result shows in Figure 10. Throughput of OFDM with BPSK modulation is 30,086

ISBN : 978-602-0917-14-6

MBps. Throughput of OFDM with 4QAM modulation is 60,269 MBps. Throughput of OFDM with 16QAM modulation is 119,188 MBps. The throughput decreases about 1 kBps than in LOS condition.

The third experiment (Obstacle 2 condition) measures the throughput of transmission streaming bits data OFDM scheme using BPSK, 4QAM and 16QAM modulation. The transmitter and receiver are placed in different rooms with distance 5m but the door between rooms is closed. In this experiment, 1 frame data is 256 bit, FFT size is 64, cyclic prefix is 64 bit and data of OFDM symbol is 192. The result is shown in Figure 10. Throughput of OFDM with BPSK modulation is 30,085 MBps. Throughput of OFDM with 4QAM modulation is 60,268 MBps. Throughput of OFDM with 16QAM modulation is 119,187 MBps. The throughput decreases about 2 kBps than in LOS condition.

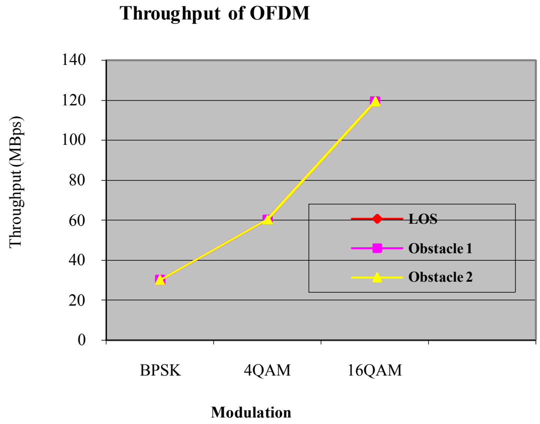

Figure 10. Throughput OFDM scheme in LOS, Obstacle1, Obstacle 2 condition

6. Conclusion

The conclusions of the Implementation OFDM using USRP with Single Carrier and OFDM Scheme Using USRP are

1. OFDM scheme hasbetter throughput than a single carrier scheme, up to 90,789 MBps.
2. The increase of modulation type can increase the throughput.
3. In OFDM scheme, there are errors between experiment and calculation. Errors of BPSK modulation is 2%. Errors of 4QAM modulation is 2,17%. Errors of 16QAM modulation is 2,95%.
4. The experiment can generate good constellation diagram of BPSK, 4QAM and 16QAM modulation.
5. LOS condition has better throughput in up to 2 kBps than in obstacle condition.

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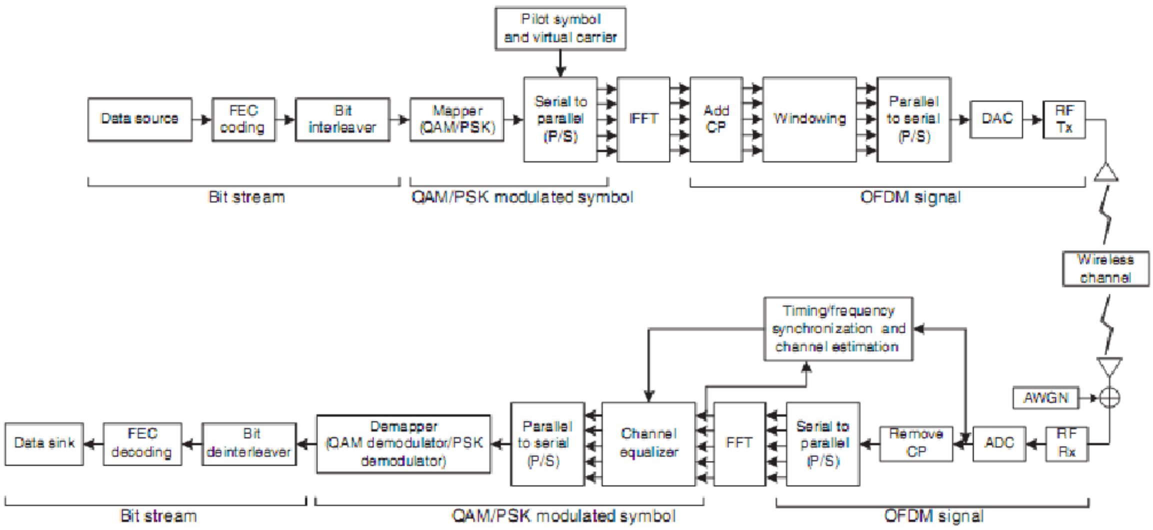

Figure 1. Block diagram of OFDM system.

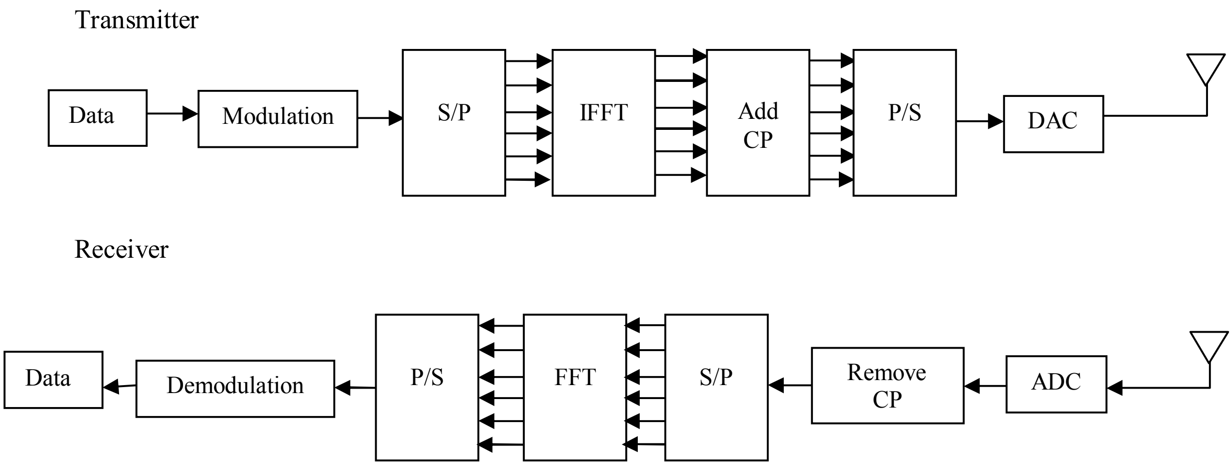

Figure 4. Block diagram of the transmitter and receiver in OFDM system.