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# An Empirical Analysis on the Effect of OFDM Parameters to the Performance of Wireless Communication System via USRP-based Transceiver

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## *Abstract*

*The configuration of parameters for OFDM scheme in standards such as the 802.11, WiMAX and LTE are varied accordingly to each system specifications. This paper offers findings from an experimental analysis carried out using wireless OFDM transceivers set-up. Experimental evaluations are indeed very useful in order to guesstimate the likely performance of any said system. Among particular system performances of interest include throughput and errors. This can be noteworthy attempt as it provides fundamental understanding and knowledge in justifying what should be the best configuration. The study had examined and quantified the effect of varying select parameters namely the modulation schemes, FFT length, and sampling rate. The use of USRP hardware as the communication testbed was extensively explored during the study. USRP sets can certainly be emerging tools for students and researchers alike to realize proof of concepts by exploiting programmable software-defined radio platforms.*

***Keywords**: OFDM; USRP; GNU Radio; Wireless Communication; Modulation; FFT; Sampling Rate*

## 1. Introduction

The upcoming "Internet-of-Things" (IoT) predicts that 26 billion devices will be interconnected wirelessly by 2020 [1]. As such, study on improving the techniques or mechanisms of current communication method such as the Orthogonal Frequency Division Multiplexing (OFDM) is always of great interest [2]. While studies of OFDM are extensively being explored through simulation approaches [3]–[8] , there is certainly limited reports of hardware-based experiments that can be retrieved [9], [10]. An experimentation analysis can be vital as it can provide a realistic references of how the communication systems will behave and perform in real-life operating environment. The traditional way of using embedded system for real experimentation without a doubt can indeed be very expensive and involve painstaking efforts. The present availability of open source software-defined radios (SDR) has offered both low development cost and flexibility to deliver the high reconfigurable requirements of communication system [11], [12]. Universal Software Radio Peripheral (USRP) [13] is a range of software-defined radios that can isolate the baseband processing from the RF parts. This has allowed the

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modification of system design to be carried out by changing configuration on software basis while retaining the same set of hardware.

## 2. Experimental Setup

The experiment conducted encompasses of SDR platforms namely two USRPs and the GNU Radio toolkits. The USRPs had been deployed as transmitter and receiver set. The transmitter was assembled using a USRP N210 with mounted CBX-40 daughterboard and connected via Ethernet gigabit cable to an i7 laptop running on Ubuntu 14.04. The GNU Radio version 3.7.9.2 facilitated the signal processing in implementation of software radios. Similar assembly was configured as the receiver with minor modification where a desktop was used instead of a laptop. The overview of the experiment setup is shown as in figure 2.

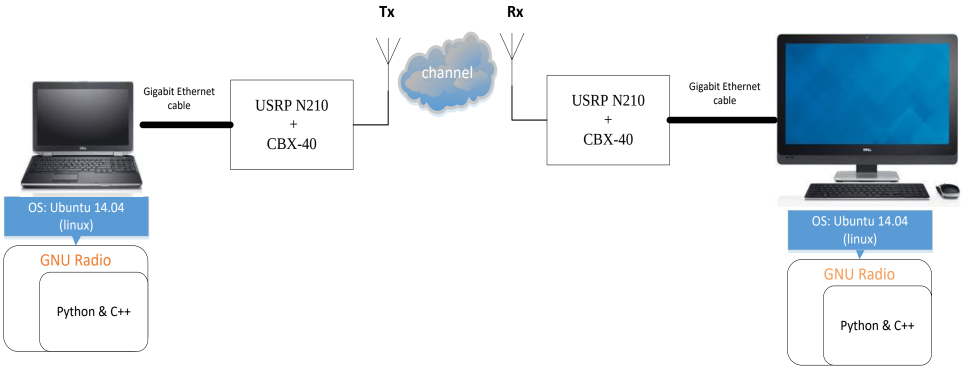

**Figure 1. Experimental Setup**

The architecture of the OFDM-based transmit and receive is depicted in Figure 3. Monopole antennas with RF center frequency of 2.45GHz were used. The separation distance between them was set at 66cm. When using USRP, there is no direct measurement value. The value for most configurable parameters is a relative value. For instance, the value of gain and amplitude can be set to any number in order to figure out the working range of the parameters as well as their corresponding real value, the output power of USRP was measured using CXA Signal Analyzer model N9000A prior to the experimentation. During the experiment, the USRP was connected to the signal analyzer tuned at 2.45GHz.

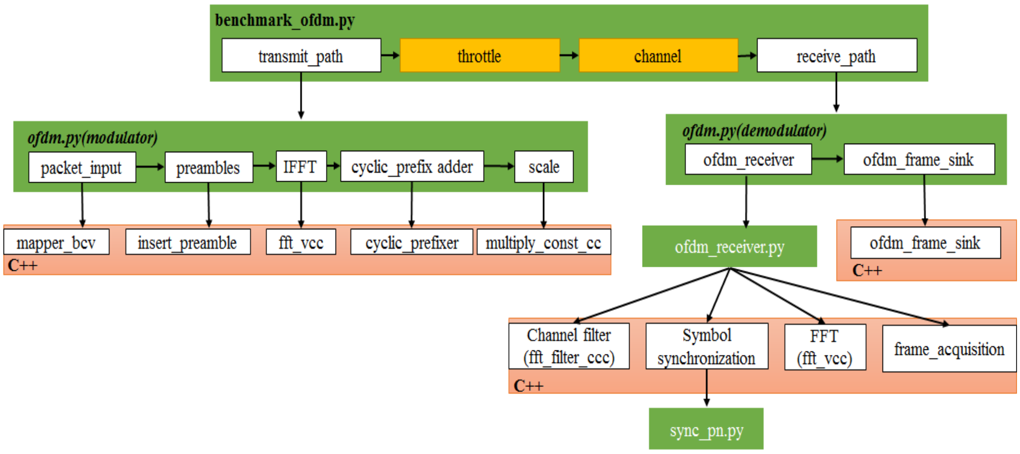

**Figure 2. Implemented OFDM Architecture**

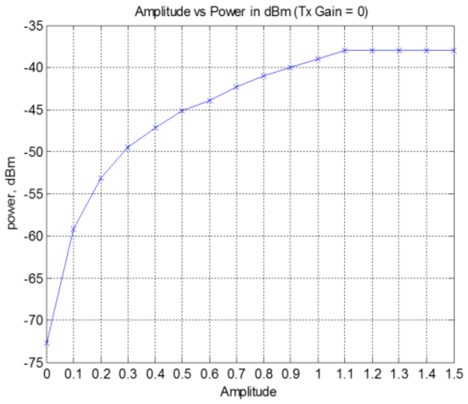

**Figure 3. USRP Output Power w.r.t Amplitude Variable**

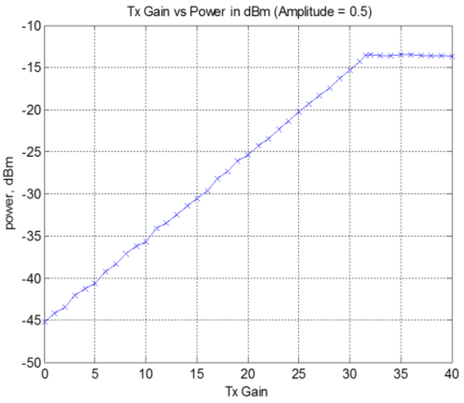

**Figure 4. USRP output Power w.r.t Gain Variable**

In Figure 4, the associated measured power is shown for amplitude0 to 1.5when gain is set to 0. It can be observed that the power continuously increases until where the amplitude value is about 1.1. For amplitude 1.1 and above, the output power appears to be constant at about -38dBm. In Figure 5, the measured power is shown for gain 0 to 40 when the amplitude is set at 0.5. From the graph, it can be observed that the power increases around 1dBm for every gain increment value until gain is 31.5. This value was regarded as the maximum gain of CBX daughterboard used in the experiment. Based on the setup, it can be regarded that the working range of the amplitude is from 0 to 1, while gain is from 0 to 31.5.

## 4. Variation of Parameters

This section outlines the findings namely change of performance values due to the effect when the OFDM parameters were varied. Three basic OFDM parameters were inspected during study, which are modulation schemes, FFT length and sampling rate. The following graphs present the percentage of either throughput or packet error at the corresponding Rx Gain with respect to the evaluated parameters:

### 4.1. Modulations

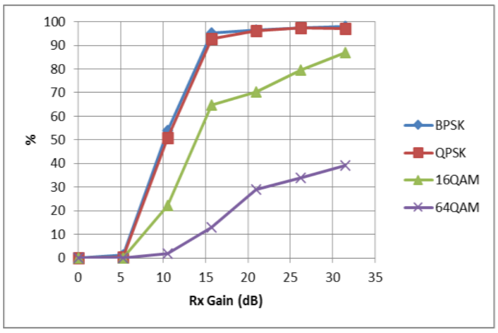

**Figure 5. Throughput of Different Modulation Schemes**

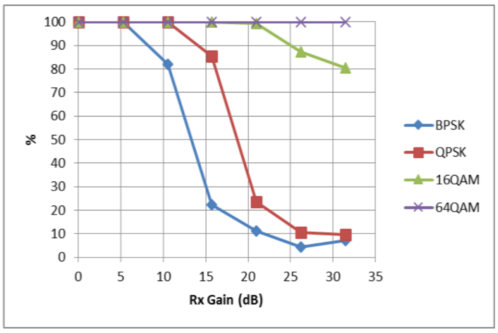

**Figure 6. Packet Error of Different Modulation Schemes**

Four modulation schemes; BPSK, QPSK, 16QAM, and 64QAM were investigated. Figure 6 and 7 represent the throughput and packet error for each of the modulation as the receiver gain was increased from 0 to 31.5. It can be observed from Figure 6 that the higher the gain, the higher the throughput. It is evident as shown in Figure 7 that the packet error reduces as gain is increased for all the modulation schemes except for 64QAM. It appeared as if all the packets experienced error.

The experimentation recorded that lower order modulation scheme of PSK shows better performance than that of QAM modulation scheme. It can be viewed that the throughput of BPSK and QPSK are almost the same. As for QAM, all the received packets appeared to be corrupted for the64QAM scheme. The graph portrays that the 16QAM outperforms the throughput of 64QAM at maximum Rx gain value. 16QAM also experienced reduced packet error of around 80%

### 4.2. FFT Length

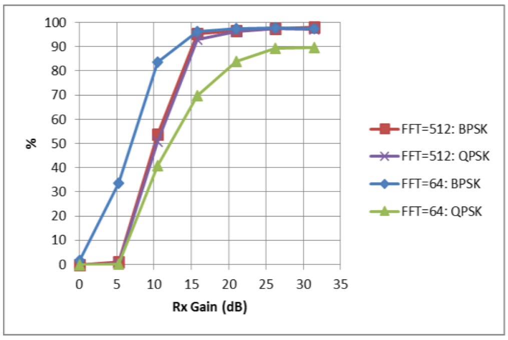

**Figure 7. Throughput of PSK in Different FFT Length**

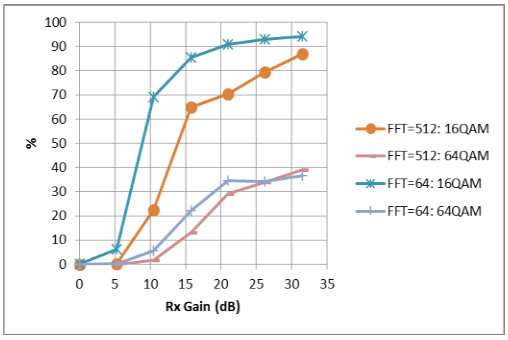

**Figure 8. Throughput of QAM in Different FFT Length**

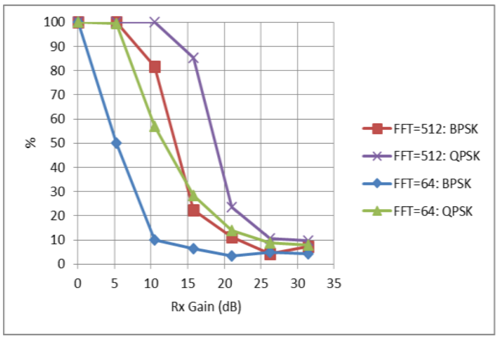

**Figure 9. Packet Error of PSK in Different FFT Length**

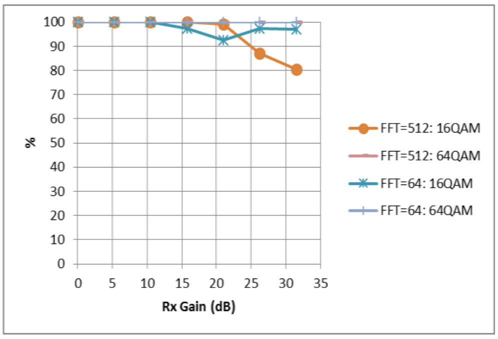

**Figure 10. Packet Error of QAM in Different FFT Length**

Two FFT lengths were chosen is this study, which are 64 and 512. These FFT lengths were put into test with four modulation techniques, which are BPSK, QPSK, 16QAM and 64QAM. Again the analyses were made in terms of throughput and packet error. Figure 8 shows the throughput for BPSK and QPSK modulation techniques when the FFT lengths were varied. From the observation of Figure 8, it can be identified that BPSK with 64 FFT length exhibits higher throughput for Rx gain above 0 dB. Figure 10 shows the packet error for BPSK and QPSK modulation techniques with different FFT lengths. From the observation of Figure 10, it can be recognized that BPSK with 64 FFT length shows the lowest packet error for Rx gain above 0 dB. Figure 9 illustrates the throughput measurements for 16QAM and 64QAM modulation techniques. From the observation of Figure 9, it can be stated that 16QAM with 64 FFT length outperforms the 64QAM. The packet error for 16QAM and 64QAM modulation techniques with different FFT lengths can be observed in Figure 11. It can be inferred that all FFT lengths with QAM modulation exhibits packet error at 100% for values of 10 dB Rx gain and below. For Rx gains between 10 dB until 22 dB, 16QAM modulation techniques with FFT length 64 shows a slightly lower packet error when compare with the rest. For Rx gain above 22 dB, the 16QAM modulation technique with FFT length 512 points out that it has the lowest packet error.

### 4.3. Sampling Rate

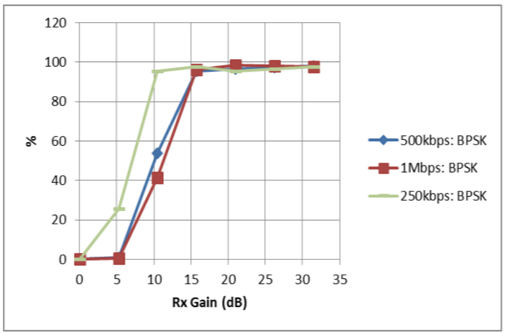

**Figure 11. Throughput of BPSK in Different Sampling Rate**

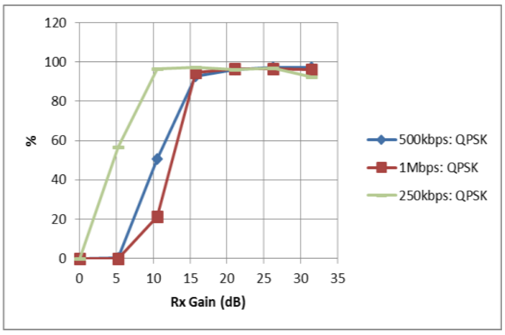

**Figure 12. Throughput of QPSK in Different Sampling Rate**

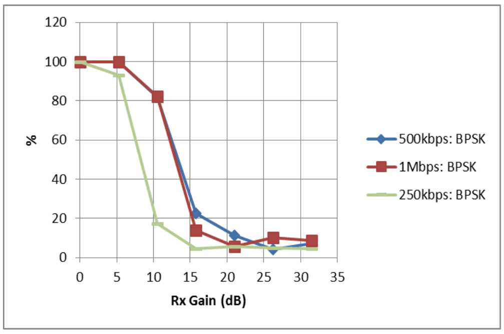

**Figure 13. Packet Error of BPSK in Different Sampling Rate**

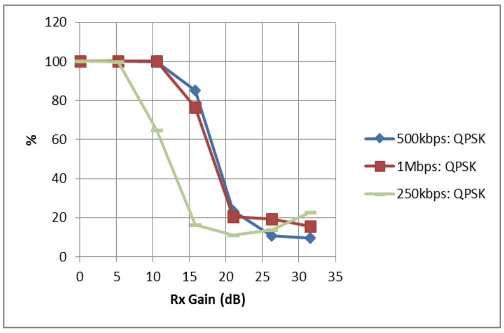

**Figure 14. Packet Error of QPSK in Different Sampling Rate**

Three sampling rate at 250 kbps, 500 kpbs and 1 Mbps were chosen in the study. The sampling rates are put into test when using two different types of modulation, which are BPSK and QPSK. From the observation of Figure 12, it can be stated that BPSK with 250 kbps has better throughput compare to the others for Rx gain values between 0 dB and 15 dB. For Rx gain above 15 dB, all sampling rates have maximum throughput at 100%. The throughput for QPSK modulation techniques with different sampling rate is plotted in Figure 13. For Rx gain values from 0 dB until 15 dB, it can be recognized that BPSK with 250 kbps has the best. All sampling rates appear to achieve maximum throughput for Rx gain above 15 dB,

Figure 14 on the other hand represents the packet error for BPSK modulation techniques with different sampling rate. For Rx gain values below 20 dB, it can be observed that BPSK with 250 kbps has lowest packet error compare to the rest. For Rx gain above 20 dB, all sampling rates show minimum packet error below 20%. The packet error for QPSK modulation techniques is illustrated in Figure 15. It was discovered that QPSK with 250 kbps has lowest packet error compare for Rx gain values below 25 dB. For Rx gain above 25 dB, all sampling rates show minimum packet error below 22%.

## 5. Comparison Analysis between Parameters

The experimental results of each tested parameters were scrutinized in order to identify how significant their effect to the system performance. For this reason, the average root-mean squared error (RMSE) and coefficient of variations of the outputs were calculated and used to deduce the aforementioned level of significance. The RMSE outlines how much the findings deviate from the ideal values which are 100% throughput and 0% error. The RMSE in this study is defined as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Theory_i - Experiment_i)^2} \tag{1}$$

where $n$ is the number of data, *Theory* is the theoretical data and *Experiment* is the measurement data. The low RMSE value is desirable as it reflects the result is closer to the maximum throughput and minimum packet error.

**Table 1. RMSE of Modulation Scheme**

| | **RMSE: Throughput (%)** | **RMSE: Packet Error (%)** |
|---|---|---|
| **BPSK** | 56.00016 | 62.56392 |
| **QPSK** | 56.59579 | 73.69532 |
| **16QAM** | 64.06329 | 95.53628 |
| **64QAM** | 84.80045 | 100 |

**Table 2. RMSE of FFT Length**

| **Modulation** | **RMSE: Throughput (%)** | | **RMSE: Packet Error (%)** | |
|---|---|---|---|---|
| | **FFT = 64** | **FFT = 512** | **FFT = 64** | **FFT = 512** |
| **BPSK** | 45.35179 | 56.00016 | 42.62132 | 62.56392 |
| **QPSK** | 59.58964 | 56.59579 | 58.93952 | 73.69532 |
| **16QAM** | 53.6692 | 64.06329 | 97.81962 | 95.53628 |
| **64QAM** | 82.47248 | 84.80045 | 100 | 100 |

**Table 3. RMSE of Sampling Rate**

| **Sampling Rate** | **RMSE: Throughput (%)** | | **RMSE: Packet Error (%)** | |
|---|---|---|---|---|
| | **BPSK** | **QPSK** | **BPSK** | **QPSK** |
| **250kbps** | 45.35179 | 56.00016 | 42.62132 | 62.56392 |
| **500kbps** | 59.58964 | 56.59579 | 58.93952 | 73.69532 |
| **1Mbps** | 53.6692 | 64.06329 | 97.81962 | 95.53628 |

Table 1-3 depict the RMSE of the system performance. From the analysis, it can be identified that the best performance of the tested configurations was achieved when the FFT length of OFDM was set to 64 with BPSK modulation. From the analysis it can be inferred that 64QAM might not be a reliable option to be deployed since it exhibited total packet error.

**Table 4. Coefficient of Variations for Comparison Between Parameters**

| | Coefficient of Variation (%) | |
|---|---|---|
| | **Throughput** | **Packet Error** |
| **Modulation Scheme** | 20.60185 | 21.45717 |
| **FFT Length** | 8.238996 | 11.05404 |
| **Sampling Rate** | 15.1232 | 10.9803 |

Coefficients of variations are used as the markers for parameters comparison. The coefficient were computed by dividing the standard deviation of each parameters to its corresponding average. The higher the coefficient variation, the more susceptible the system to the changes of tested parameters. From Table 4, modulation scheme gives the highest variation followed by sampling rate and finally FFT length. In other words, modulation scheme is the most significant parameter to the performance of the tested wireless system.

## 6. Conclusion

The findings present prospect of hardware platforms in the assembly of OFDM systems. The setup can incorporate multipath propagation model as a separate system or as a single system readied for analysis. The acquired digital constellation plots and FFT spectrums match the expected theoretical results. Therefore, the study concluded that SDR can be exploited to model OFDM scheme in applications such as WiFi, WiMAX and others. It is noted that although all the parameters in the experiment were set prior to the system execution, the results comply with the theoretical trends. The results suggest that modulation scheme should take priority over other parameters since it dominates the system performance. In a nutshell, appropriate modulation scheme must be on the top consideration followed by other parameters when designing the best OFDM scheme for wireless system.

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