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OFDM Simulation Using Different Modulation Techniques with MATLAB

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Abstract — Our project "OFDM Simulation Using Different Modulation Techniques With MATLAB" is primarily intended to develop a MATLAB-based simulation of OFDM, i.e. Orthogonal Frequency Division Multiplexing, and using various other modulation techniques like QPSK, BPSK, and so on, and compare its system parameters errors with the OFDM methodology of Modulation, as some variables are entered by the user. The remaining variables are either fixed or derived from user input and fixed variables. Among the user input variables are:

1) Input file (to be taken from the user) – an 8-bit grayscale (256 gray levels) bitmap file (*.bmp file);
2) IFFT size – an integer of a power of 2;
3) No. of carriers to be present – not greater than [(IFFT size)/2 – 2];
4) Digital modulation techniques – BPSK, QPSK, 16-PSK, or 256-PSK;
5) Signal peak power clipping to be measured in dB;
6) Signal_to_Noise Ratio (SNR) measured in dB.

The structure and implementation of an OFDM modem used in wireless communication are discussed in this paper. Orthogonal recurrence rate Division Multiplexing (OFDM) is one of the most recent modulation techniques used to combat frequency-selectivity in transmission channels while achieving significant data rates with no inter-symbol disturbance. This technique is used in bandwidth-intensive applications such as video conferencing, DAB, DVB, and many others. The use of MC-CDMA allows for multi-user capacity. OFDM refers to a group of techniques that have been proposed for use in 4th Generation cellular systems. The majority of the time, orthogonal. In multipath environments, conventional techniques such as QAM have very high bit error rates and ISI, which can be reduced by implementing the OFDM technique. Nevertheless, the application is limited by the presence of a potentially high peak-to-average electrical power ratio (PAPR).**(1).**

1. INTRODUCTION

OFDM is multicarrier system, similar to that of the FDM (Frequency Division Multiplexing), divides the entire available information measure in the spectrum into sub-bands for multiple carriers to transmit in parallel. By putting carriers close together in the spectrum, an overall high rate will be achieved. However, inter-carrier interference (ICI) can occur due to a lack of space between the carriers. To avoid inter-carrier interference, guard bands should be placed between any adjacent carriers, resulting in reduced knowledge data rates.

OFDM (also known as Orthogonal Frequency Division Multiplexing) is a multicarrier digital communication theme that can be used to solve each problem. It assembles an oversized assortment of low-rate carriers to form a composite high-data-rate communication system.

Orthogonality (In a nutshell, two signals are orthogonal if the inner product between them is 0) plays as one of the major reason for carriers to be spaced very closely, even overlapped sometimes, but is not creating the inter-carrier interference nor the ISI.**(1,2)**. As here in each carrier's data rate is low, symbol periods are long, which reduces inter-symbol interference significantly also we are using the concept of the Frame Guards.

Although the concept of OFDM was very first proposed into 1966, it was not widely used until the last decade, when it finally became the very modern modem of choice in wireless applications. It is now intrigued enough to investigate the inner workings of OFDM.

Various kinds of Orthogonal Frequency Division Multiplexing (OFDM)-based waveforms have been used in this standard and many other networks in recent years due to the numerous benefits they provide. Despite being completely compatible with Multiple Input Multiple Output (MIMO) systems, being simple to build with the use of the Fast Fourier Transform (FFT), the immunity of OFDM systems to frequency selective fading channels, efficient modulation and demodulation, and so on, OFDM-based systems have many limitations.

Some of these limitations include the need for strict synchronisation between the Tx and Rx in order for the system to function properly, the large Peak to Average Power Ratio (PAPR), and the high power and bandwidth losses caused by the use of guards bands.

OFDM is one of the most well-known techniques for meeting the growing demand for high-data-rate transmission in both wired and wireless modes of communication. The various applications of the OFDM system are illustrated below.

- Digital audio broadcasting (DAB)
- LTE cellular-telecom standards
- WI-FI arena, where standards such as IEEE 802.11a, 802.11n, 802.11ac, and so on are used immensely.
- An ATM transmission system that is wireless.

2. SIGNIGICANCE

The OFDM technique will have an impact on the future of communications. With the recent expansion of digital communication processes, the demand for high-speed information transmission has grown. It is only recently that advancements in integrated world technology have made the specific implementation of OFDM feasible and cost-effective. New multicarrier modulation techniques, such as OFDM, are currently being implemented to keep up with the demand for increased communication capacity. GSTN (General Switched Telephone Network), cellular stereo, DSL and ADSL modems are a few examples of current applications that use OFDM. The primary parameters of the OFDM are listed in Table 1. The Frame Guard having an interval of approximately 800 ns, **(3)** generally provides an ultimate robustness to the root-mean-squared delay spreads of various hundreds of nanoseconds, this is essentially a key parameter that heavily influenced the selection of the other guidelines.

Table 1: Main Parameters of the OFDM standard

Modulation	BPSK, QPSK, 16-QAM, 64-QAM
Data rate	6, 9, 12, 18, 24, 36, 48, 54 Mbit/s
Number of subcarriers	52
Coding rate	1/2, 2/3, ¾
OFDM symbol duration	4 µs
Number of pilots	4
Subcarrier spacing	312.5 kHz
Protect interval	800 ns
Channel spacing	20 MHz
-3 dB Bandwidth	16.56 MHz

3. ORTHOGONALITY

Orthogonal Frequency Division Multiplexing (OFDM) is essentially a multicarrier transmission technique that will divide the entire bandwidth into many carriers often called sub-carriers, each of which is modulated by a low-rate data stream. In terms of multiple entry technique, OFDM is similar to FDMA (frequency division multiple access) in that multiple user gain access is achieved by subdividing the available bandwidth into multiple channels, which are then allocated to end users. Signals are orthogonal if they are mutually independent of one another. Orthogonality is basically defined as the property that allows multiple information signals to be transmitted and detected perfectly over a typical channel without any kind of interference. Loss of orthogonality results in data signal blurring and communication degradation.(4).

Various common multiplexing systems are orthogonal by definition. Time Division Multiplexing (TDM) enables the transmission of multiple information signals on a single channel by allocating distinct time slots to each separate information signal. Only the signal from a single source is transmitted during each time slot machine game, preventing any interference from multiple information sources.

As a result, this TDM is orthogonal to nature. Most FDM systems are orthogonal in the frequency sector because the individual transmission signals are generally well spaced out inside Frequency, preventing interference. For orthogonal functions, if any two different functions in the set are multiplied and integrated over a symbol period, the result is zero.(8).

Equation (1) depicts a set of orthogonal sinusoids that represent the unmodulated OFDM signal's subcarrier.

Sk(t) equals Sin(2k f0t). 0tT where k=1,2,3…. = 0 else (1)

ALSO, f0 denotes carrier spacing, and M denotes the number of carriers.

T = period symbol

Because the highest rate of recurrence component is Mf0, the transmission bandwidth can also be Mf0, resulting in orthogonal frequency components.(5,6).

4. SIMULATION FLOWCHART

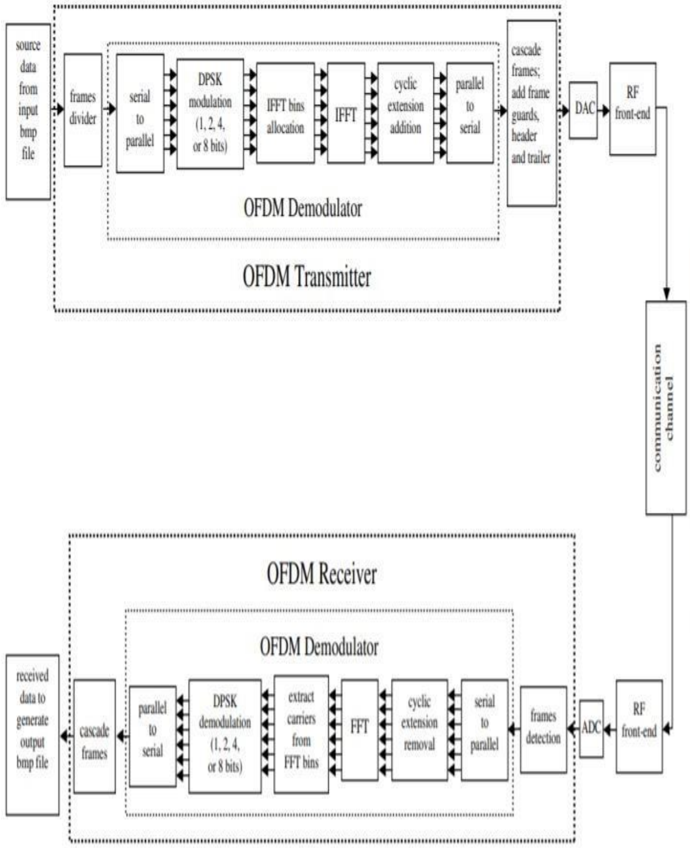

Figure 3 – Block Diagram of an OFDM System

5. SYSTEMCONFIGURATIONAND PARAMETERS (To Be Entered By User)

A very important script file named ofdm parameters.m is invoked at the start of this simulation MATLAB programme, which initialises all required OFDM parameters and programme variables to begin the simulation. The user enters a few variables. The remaining variables are either fixed or derived from user input and fixed variables. Among the user input variables are:

1) Input file to be executed – an 8-bit grayscale (256 grey levels) bitmap file (*.bmp);
2) IFFT size to be executed – a power of two integer;
3) The number of carriers must be less than [(IFFT size)/2 – 2];
4) Digital modulation method to be used as – BPSK, QPSK, 16-PSK, or 256-PSK;
5) Signal peak power clipping in decibels (dB);
6) Signal-to-Noise Ratio in decibels (dB), etc.

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All user-inputs are checked for validity and after verification completes the program will request the user to correct any incorrect fields with brief guidelines provided. An example is shown in Table 1.(9). This script of MATLAb also demonstrated very well how the carriers and its conjugate carriers are finely allocated into the IFFT bins, based on the above provided IFFT size and number of carriers that had been defined by the users.

```
##########################################
#*********** OFDM Simulation ************#
##########################################

source data filename: abc
"abc" does not exist in current directory.
source data filename: cat.bmp
Output file will be: cat_OFDM.bmp
IFFT size: 1200
IFFT size must be at least 8 and power of 2.
IFFT size: 1024
Number of carriers: 1000
Must NOT be greater than ("IFFT size"/2-2)
Number of carriers: 500
Modulation(1=BPSK, 2=QPSK, 4=16PSK, 8=256PSK): 3
Only 1, 2, 4, or 8 can be choosen
Modulation(1=BPSK, 2=QPSK, 4=16PSK, 8=256PSK): 4
Amplitude clipping introduced by communication channel (in dB): 6
```

Table 1 – User Input Validity Protection

6. ERROR CALCULATIONS

Data Loss Error

As mentioned in "Input and Output," one or more full rows of pixels may be missing at the receiver's output. In such cases, the programme would display the number of missing data and total data transmitted, as well as the percentage of data loss, which is the quotient of the two.(1).

Bit Error Rate (BER)

The total number of errors is calculated by comparing the demodulated data to the original baseband data. The bit-error-rate (BER) is calculated by dividing the total number of errors by the total number of demodulated symbols. (1).

OFDM System Phase Error

Before being translated into symbol values, the received phase matrix is archived during OFDM demodulation in order to calculate the average phase error, which is defined as the difference between the received phase and the translated phase for the corresponding symbol before transmission. (1).

Pixel Error as a Percentage in the Received Image in OFDM Systems

All of the previous error calculations are based on OFDM symbols. The actual percent error of pixels in the received image is more meaningful to the end-user of the OFDM communication system. This is accomplished by comparing the received and original images pixel by pixel. (1).

```
#**************** Summary of Errors ****************#
Data loss in this communication = 0.125000% (1200 out of 960000)
Total number of errors = 1174 (out of 958800)
Bit Error Rate (BER) = 0.122445%
Average Phase Error = 1.877366 (degree)
Percent error of pixels of the received image = 0.257708%
```

Table 3 – Error Calculations

– Screen Log

```
>> OFDM_SIM

##########################################
#*********** OFDM Simulation ************#
##########################################

source data filename: cat.bmp
Output file will be: cat_OFDM.bmp
IFFT size: 2048
Number of carriers: 1009
Modulation(1=BPSK, 2=QPSK, 4=16PSK, 8=256PSK): 2
Amplitude clipping introduced by communication channel (in dB): 9
Signal-to-Noise Ratio (SNR) in dB: 12

Summary of the OFDM transmission and channel modeling:
Peak to RMS power ratio at entrance of channel is: 15.485296 dB
Peak to RMS power ratio at exit of channel is: 10.143752 dB
#******** OFDM data transmitted in 13.630532 seconds ********#

Press any key to let OFDM RECEIVER proceed...
Demodulating Frame #1
Demodulating Frame #21
Demodulating Frame #42
Demodulating Frame #63
Demodulating Frame #84
Demodulating Frame #105
Demodulating Frame #126
Demodulating Frame #147
Demodulating Frame #168
Demodulating Frame #189
Demodulating Frame #210
Demodulating Frame #212
#********** OFDM data received in 8.171716 seconds *********#


#**************** Summary of Errors ****************#
Total number of errors = 13077 (out of 1920000)
Bit Error Rate (BER) = 0.681094%
Average Phase Error = 12.335541 (degree)
Percent error of pixels of the received image = 1.796667%

##########################################
#******** END of OFDM Simulation ********#
##########################################

>>
```

Table 6 – OFDM Simulation Log

7. SIMULATION PLOTTINGS

During this OFDM simulation, seven graphs are plotted:

1. OFDM carrier data magnitudes on IFFT bins;
Because all magnitudes are ONE, what this plot really demonstrates is how the carriers are distributed in the IFFT bins.

2. Phases translated from OFDM data;
The original data has a number of possible levels equal to 2 raised to the power of symbol size, as shown in this graph.

3. Modulated time signal on a single carrier for one symbol period;

4. Modulated time signal for one symbol period on multiple carriers (limited to six);

5. The magnitudes of the received OFDM spectrum;
Comparison to the first graph.

6. Phases of the received OFDM spectrum;
Compare with the second graph.

7. Polar plot of the received phases;
For successful OFDM transmission and reception, this plot should clearly show the grouping of the received phases into 2symbol-size constellations.

TRANSMITTER PLOTS of Project

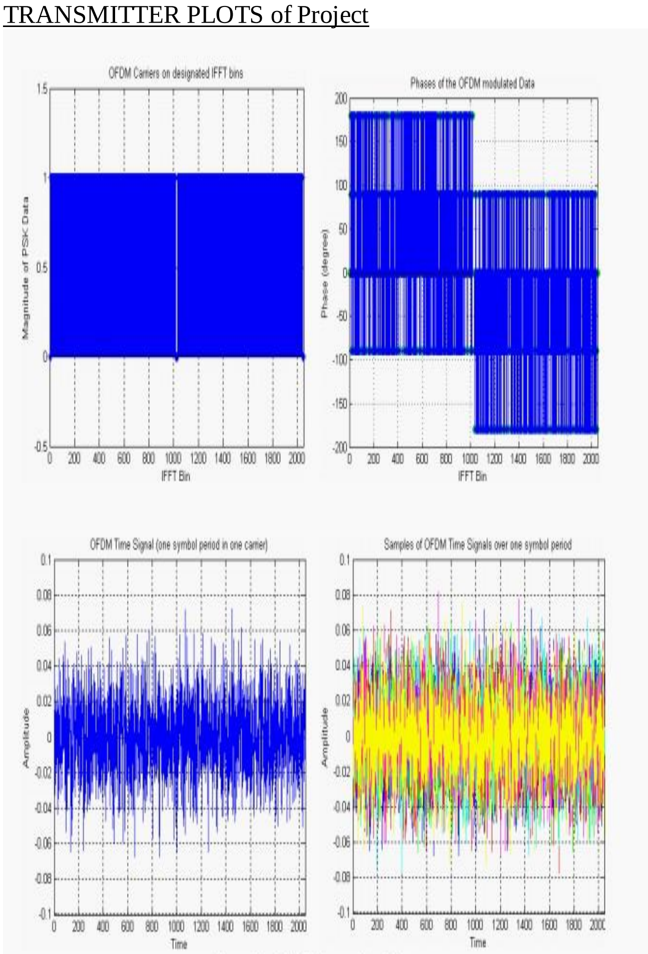
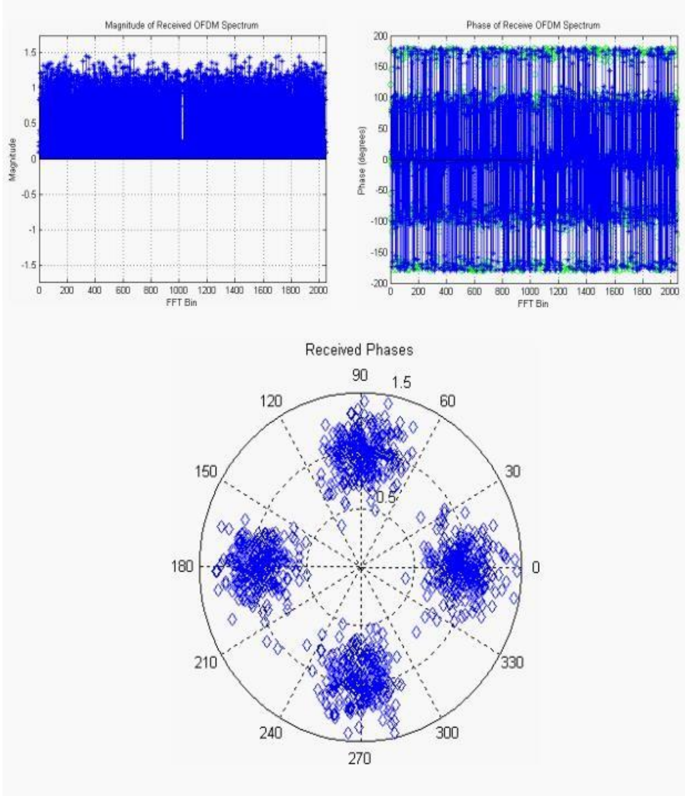


Figure 25 – OFDM Transmitter Plots



8. OFDM SYSTEM's INPUT AND OUTPUT IMAGES

Figure 24 – Original Image

Figure 23 – OFDM Received Image

9. OFDM SYSTEM's APPLICATIONS (THAT CAN BE DERIVED FROM PROJECT)

The OFDM technique is probably the most well-known technique in this type of communication system. Some of its applications are listed below.

1. DAB: DAB - OFDM is the foundation for the Digital Audio Broadcasting (DAB) standard in the European market, and it is the next step beyond FM radio broadcasting in terms of interference-free transmission.**(7).**
2. High Definition Tele-Vision
3. Wireless Local Area Networks
4. HIPERLAN/2 3.1 IEEE 802.11g
5. IEEE 802.16 Broadband Wireless Access System is a wireless access system that provides high-speed Internet access over a wide range of frequencies
6. ATM transmission system that is wireless
7. IEEE 802.11a (Wi-Fi)

10. CONCLUSION

Here a complex OFDM system involving its transmitter and its receiver is successfully simulated with the help of MATLAB software. All of the major components of an OFDM system are discussed here. This has demonstrated the fundamental concept and viability of OFDM.

Some of the challenges in developing this OFDM simulation programme included carefully matching modulator and demodulator steps, keeping track of data format and data size throughout all simulation processes, designing a complex yet simple but appropriate frame detector for the receiver, and debugging the MATLAB codes.

We made every effort to explain some analyses of the performance and characteristics of this simulated OFDM system in this section. It was discovered that for some of the OFDM parameter combinations and patterns, the simulation may fail for some trials but succeed for subsequent trials with the same parameters. It is because the random noise generated on each and every trial conditions varies, and some certain random noise may have caused problems for the frame detector in the OFDM receiver.

Debugging the issues and further making the frame detector error-free will require additional work in the future. Other potential future enhancements to this simulation programme include the ability to accept input source data in word sizes other than 8-bit and the option to use QAM (Quadrature amplitude modulation) as the modulation method rather than M-DPSK.

This paper demonstrates that OFDM is far better suited to a multipath channel than traditional single carrier transmission methods like 16-QAM. The desire for high data rate wireless communication has grown dramatically over the last decade. This paper investigated the role of OFDM in wireless communication and its advantages over single provider transmission. There are a few limitations to this technique that are frequently removed with the guidance of suitable techniques.

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