Simulation of Channel-estimation for Digital Communication System based on OFDM

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ABSTRACT- OFDM is among the most advanced techniques which are used in digital communication systems for transmitting digital data in an efficient manner. In this manuscript, the characteristic of a sine function is used to transforms a signal in a baseband into a carrier bandwidth. The modulation/ demodulation techniques such as BPSK, QPSK, 16-PSK and 256-PSK are applied on the source data, in this case a 2-D gray-scale image. As the results, the estimation of this OFDM system is acceptable, up to a certain level of additive noise in the channel that is, if the noise level is raised above the critical level, the performance of the system may not vary rapidly. Within the OFDM system, different modulations techniques are employed for evaluation and essential conclusions have been made from the comparison of several MATLAB simulations.

Keywords: OFDM, AWGN, BPSK, QPSK, 16-PSK, 256-PSK.

I. INTRODUCTION

During the early years of development of these communication technologies, the data and the modulation techniques used were all based on analogue technology with analogue signal processing methods being slot in the systems. With the onslaught of digital technology and techniques in the 1960s and 1970s, the wireless transmission system began to evolve further. The digital era allowed the digitization of analogue signals to occur which opened the door to the progress of signal processing using digital hardware and software devices (DSP) and digital modulation techniques to efficiently transmit these digital data streams.

In a single carrier communication, the symbol duration must be much larger than the time-delay of carrier signals in order to avoid inter-symbol interference [1] (ISI). The main advantage of single carrier modulation (SCM) with frequency domain linear equalization is the reduced peak-to-average power ratio of the broadcasted signal. Since the data transmission speed is inversely proportional to the duration of the symbol, the duration of a small symbol indicates high data transmission speed and communication efficiency. While in a multi-carrier system, such as FDM (Frequency Division Multiplexing), divides the entire bandwidth into the spectrum of sub-bands for multiple carriers transmitted in parallel[6]. A high data transmission speed can be achieved by positioning the operators near the spectrum. However, the dispersion of a carrier signal beyond its range will cause interference with adjacent carriers, termed as inter-symbolic interferences. It happens because of the lack of space between the carriers. To avoid inter-symbolic interference, it is necessary to insert a prefix extension (guard bands) between each adjacent carrier, which results low transmission speed.

OFDM (Orthogonal Frequency Division Multiplexing) is a unique digital multi-carrier communication method to solve both the problems as mentioned above. Orthogonal Frequency Division Multiplexing using BPSK, QPSK, 16-PSK and 256-PSK for image transmission has been studied by taking into account the following points:

a) Minimizing the value of Peak-to-R.M.S. Signal Ratio (PRSR) and Bit Error Rate (BER) [4].

b) Increase the system's bit rate capability and Signal-to-Noise Ratio (SNR).

The motto of this proposal is to demonstrate the concept and viability of an OFDM system and to estimate how its performance is modified by changing some of its main parameters. In this paper, the OFDM system is analyzed in Section II, Error Calculations in Section III, Test Results in Section IV and Conclusion in Section V.

II. OFDM DIGITAL SYSTEM

In the digital communication system, OFDM data are generated by taking the symbols in the frequency-domain using M -PSK and convert it into the time-domain spectrum by taking the Inverse Fast Fourier Transform (IFFT). Once the OFDM data is modulated on the time signal, all the carriers in spectrum transmitted in parallel to fully occupy entire available bandwidth. During modulation, OFDM bits are generally grouped into frames, so that the data is modulated frame by frame so that the received signal is synchronized with the receiver [5]. Long symbol duration reduce the likelihood of interference between symbols, but cannot eliminate them. To make ISI almost eliminated, a cyclic prefix/extension is added to each symbol durations. It allows the demodulator to acquire the symbol period with an uncertainty up to the cyclic extension and still obtain the correct information for the entire period of the symbol.

As shown in Figure 1, a cyclic extension (guard band), is the amount of uncertainty allowed for the receiver to acquire the starting point of a symbol period, such that the result of FFT still has the correct information.

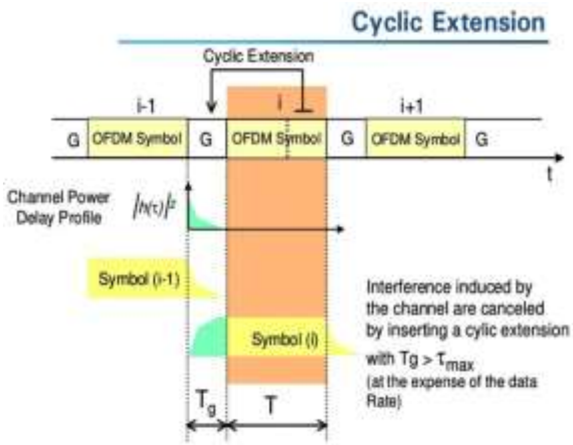


Figure 1: Cyclic Extension Tolerance

a) Implementation of OFDM System

Figure 2 shows a block diagram of an OFDM system. The source data for simulation is taken as an 8-bit grayscale bitmap image file (256 levels of gray) depending on the user's choice. The image data will be converted to the symbol size (bit/symbol) determined by the choice of M-PSK of four variations provided by this simulation.

The converted data will be separated in multiple frames by the OFDM transmitter. The OFDM modulator modulates the data frame per frame. Before the transmitter is emitted, the modulated frames of the time signal are cascaded with the guards of the frames inserted between them, as well as a pair of identical headers are added at the beginning and at the end of the data flow. The communication channel is modeled by adding the white Gauss noise and the effect of changing the size of the amplitude (clipping).

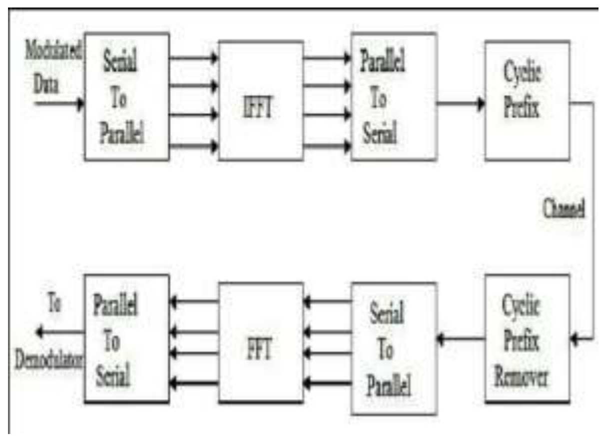


Figure 2: Block diagram of an OFDM system

The receiver detects the beginning and end of each frame in the signal received by an envelope detector. Each detected time signal is demodulated into useful data. Modulated data is converted into 8-bit word-size data used to generate a simulation output image file. OFDM combines a large number of low speed data carriers to build a composite system for high speed data communications. Low data rate of each carrier implies long symbol periods, which greatly diminishes inter-symbol interference.

The orthogonality provides the carriers with a valid close-up, even overlapping, without inter-symbolic interference [3] . The low data transmission rate of each vector implies long periods of symbols, which greatly reduces the interference between symbols. The error calculations are made at the end of the program. Representative diagrams are shown during the execution of this simulation in section IV.

b) System Configurations and Parameters

At the beginning of the simulation MATLAB program, a script file that initializes all OFDM parameters and the variables to start the simulation. Some variables are entered by the user and the remaining are either fixed or derived from user-input and fixed variables.

The user-input variables include:

Parameter	Values
Input file	8-bit grayscale bitmap
IFFT size	1024

Number of carriers	500
Digital modulation	BPSK, QPSK, 16-PSK and 256-PSK
Signal peak power clipping	3 dB
Signal-to-Noise Ratio	0 dB to 70 dB

The number of carriers must not be greater than [(size of IFFT)/2 – 2], because there are as many conjugate carriers as the carriers, and an IFFT bin is reserved for DC signal while other IFFT bin is for the symmetrical point at the frequency of Nyquist to separate carriers and conjugate carriers.

c) Input and Output

The program reads source data from an input image file and obtains an *h*-by-*w* array where *h* is the image's height and *w* is its width (in pixels).This array is reorganized into a serial data stream. Since the input image is an 8-bit gray-scale bitmap, its word size is always being 8 bits/word[7]. The source data will then be converted to the symbol size corresponding to the order of PSK chosen by the user. It converts the original 8-bits/word data stream to a binary array with each column representing a symbol in the symbol size of the selected PSK order. This binary array will then be converted into the data stream with a symbol size, which is the baseband for accessing the OFDM transmitter.

At the output of the OFDM receiver, a stream of demodulated data needs to go through the base conversion again to return to 8-bits/word. This time, since the PSK symbol size could be less than 8 bits/symbol, a script file, *ofdm_base_converterm* would cut the data stream to a multiple of 8/symbol-size before the base conversion to allow each one to convert some symbols have enough bits. If the OFDM receiver does not detect all the data frames at the exact locations, the demodulated data may not be of the same length as the transmitted data stream.

d) Communication Channel

Two properties of a typical communication channel are modeled. The user configures a cut variable in this MATLAB program. The maximum power cut is basically setting any data points with values over clipping below peak power to clipping below peak power. The relationship between the peak and the RMS of the signal at the entrance and at the exit of the channel are shown for comparison with respect to this effect of saturation of the maximum power.

An example is shown in Table 2.

Summary of the OFDM transmission and channel modeling:

Peak to RMS power ratio at entrance of channel is: 15.342979 dB

Peak to RMS power ratio at exit of channel is: 14.723989 dB

#***** OFDM data transmitted in 28.009282 seconds ******#**

Table 2: OFDM Transmission Summary

Channel noise is modeled by adding a white Gaussian noise (AWGN) defined by:

Standard Deviation (σ) of AWGN

=sqrt(variance of modulated signal/linear SNR)

It has a mean of zero and a standard deviation equal to the square root of the quotient of the variance of the modulated signal over the linear Signal-to-Noise Ratio, whose value in dB is also set by the user.

III. ERROR CALCULATIONS

a) Data Loss

As in "Input and Output," one or more complete rows of pixels may be missing at the receiver's output. In these cases, this program would show the amount of data lost and the total number of data transmitted, as well as the percentage of data loss, which is the quotient of the two.

b) Bit Error Rate (BER)

The demodulated data are compared with the original baseband data to find the total number of errors. By dividing the total number of errors by the total number of demodulated symbols, the bit-error-rate (BER) is calculated.

c) Phase Error

During the OFDM demodulation, before being converted into symbol values, the received phase array is archived for calculating the average phase error, which is defined by the difference between the received phase and the translated phase for the corresponding symbol before transmission.

d) Percent Error of Pixels in the Received Image

All the above mentioned error calculations are based on the OFDM symbols. What is most significant for the end-user of the OFDM communication system is the error rate of the actual pixels in the received image. This is done by comparing the received image and original image pixel by pixel.

A summary showing the previously mentioned error calculations is shown at the end of the program. In an example shown in Table 3, an 800-by-600 image is transmitted by 500 carriers using an IFFT size of 1024, through a channel with 5 dB peak power clipping and 30 dB SNR white Gaussian noise.

#************** Summary of Errors ****************#**

Data loss in this communication = 0.416667% (4000 out of 960000)

Total number of errors = 40610 (out of 956000)

Bit Error Rate (BER) = 4.247908%

Average Phase Error = 4.415811 (degree)

Percent error of pixels of the received image = 8.335425%

Table 3: Error Calculations

IV. TEST RESULTS

A Simulation test by OFDM configuration shown in Table 4.

Parameters	Values
Source Image Size	800*600
IFFT size	1024
Number of Carriers	500
Modulation Method	QPSK
Peak Power Clipping	3dB
Signal to Noise Ratio	10dB

Table 4: Parameters of Simulation

As the amplitude of the receipt data is not as flat as the original, while maintaining the same pattern. By reducing the number of carriers and the IFFT size to about half, while all other parameters remain the same, the simulation runtime for both the transmitter and receiver does not seem to vary much. It is because the simulation program monitors the total number of symbols to form one frame of data, so the total number of frames does not differ much.

The measured execution time depends on the number of computer operations, which directly depends on the number of data frames that must be modulated and demodulated for a fixed number of symbols per frame. In conclusion, this measurement of the execution time does not reflect the change in efficiency as a function of the variable numbers of carriers.

However, it is significant to use this measure to understand the change in efficiency as a function of various PSK orders. The execution times have been tripled for a simulation with BPSK while other parameters remain the same. A graph in Figure 3 shows that using 16-PSK and 256-PSK also validate this theory.

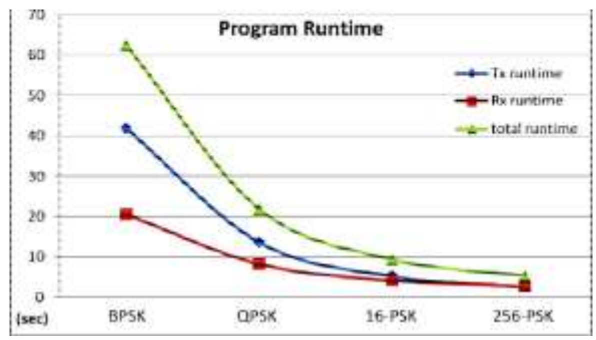


Figure 3: Program Runtime

However, as shown in Figure 4, BER massively increased by increasing the order of PSK, as a compensation for the reduction of execution time.

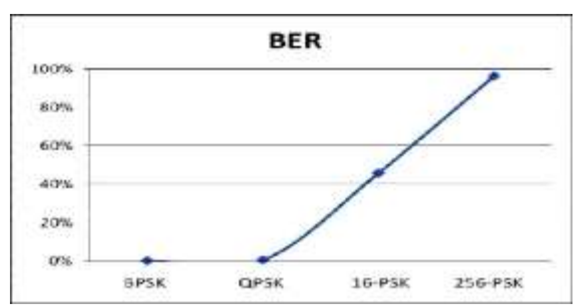


Figure 4: BER vs. *M*-PSK

As, the SNR is inversely proportional to error rates[2]. The implemented performance analysis method has been described in terms of PRSR (Peak to Root-mean-square

Signal Ratio), Pixel Error, BER (Bit Error Rate) and transmission time as given in Table 5.

Parameters	Values
Source Image Size	800*600
IFFT size	1024
Number of carriers	500
Modulation method	QPSK
Peak Power Clipping	3dB
Signal to Noise Ratio	0dB

Table 5: Parameters of Simulation of Errors

Figure 5 represents the relationship between the BER and SNR for all the four Mth-PSK methods. As expected, higher order PSK needs a larger SNR to minimize BER.

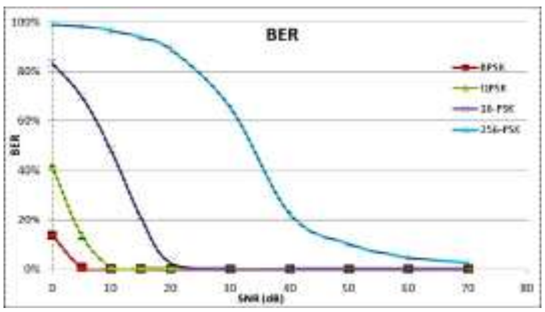


Figure 5: BER vs. SNR

Likewise, as shown in Figure 6, 256-PSK and 16-PSK requires a relatively large SNR to transmit data with an acceptable pixel percent error.

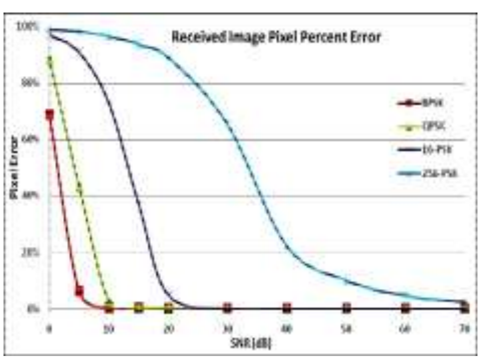


Figure 6: Pixel Error vs. SNR

Figure 7 shows the original image to be transmitted over the OFDM system.

Figure 7: Original Image

The figures of the images received for different orders of PSK with varied SNR are shown in Table 5.

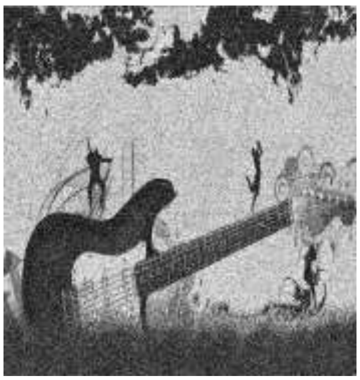
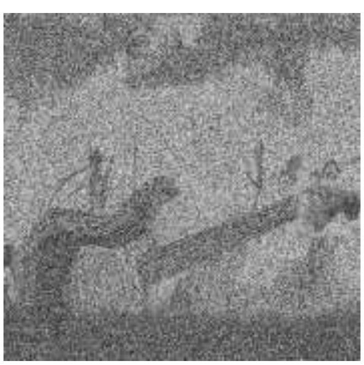
As per expectations, when the size of the OFDM symbol is not equal to the word size of the source data that is, some images with low SNR reception, in particular images modulated at 256-DPSK, have rather high BER but most of the information in the received images is still observable. For example, at 10 dB of SNR, although the received image of 256-PSK had a BER of 93.63%, the image remains still observable. It is so, because for gray-scale digital images, if the decoded value of a pixel is disabled by a small number of gray levels, it's not easily observed by human eye, but will be considered as a bit error.

In fact, alternating between the original image and the one received image in this case, it is obvious that the gray level in most of the pixels has changed, but the contents are relatively still quite intact. It is necessary to find a balanced compensation between BER-tolerance and data rate desire for the type of data to be transmitted using OFDM.

It was found that OFDM's SNR performance is similar to that of a standard single carrier digital transmission. It is to be expected, since the transmitted signal is similar to a standard FDM system. The results show that when using 16-PSK the transmission can tolerate a SNR of >25-30dB.

The BER gets deteriorates rapidly as the SNR falls below 6dB. However, using QPSK makes it possible to improve the BER in a noisy channel, at the expense of data transmission capacity. Using QPSK the OFDM transmission can tolerate a SNR of >20-25dB. In a low noise link, using 16-PSK can increase the channel capacity.

If the SNR > 25dB, 16-PSK can be used, and also it can double the data capacity as compared to QPSK. For this simulation the OFDM signal had been tested with a multipath signal with a single reflected echo. It can be seen that the BER is very low for a delay spread of less than about 256 samples. As in a practical system (i.e. one with a 1.25 MHz bandwidth), its delay propagation would correspond to ~80 msec. This delay propagation would be for a reflection with 24 km extra path length. It has been found that the transmitted OFDM signal could be too cut with little effect on the received BER. Actually, the signal could be cut to 9dB without a significant increase in the BER. This means that the signal is highly cut-resistant to distortions caused by the power amplifier used in the signal transmission. It also means that the signal can be purposely clipped by up to 12 dB so that the peak to RMS ratio can be reduced following an increased transmitted power.

BPSK	**0 dB** 	**3 dB** 	**5 dB** 
QPSK	**0 dB** 	**5 dB** 	**10 dB** 
16-PSK	**0 dB** 	**10 dB** 	**20 dB** 

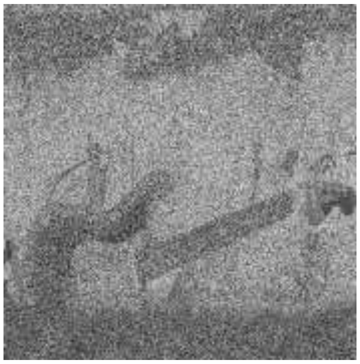
	0 dB	**30 dB**	**70 dB**
256-PSK			

Table 5: Images received for different orders of PSK with varied SNR

III. CONCLUSION

An OFDM system with MATLAB successfully simulated in this project. All the main components of an OFDM system are covered. This turned out to be the basic concept and viability of OFDM, which was described and explained in section 2 of this paper. Some of the challenges in developing this simulation program have been carefully adapting the matched steps in the modulator and the demodulator, by keeping track of data format and data size throughout all the processes of the entire simulation, designing an appropriate frame detector for the receiver, and debugging the MATLAB codes. Section 4 explained some analyses of the performance and characteristics of this simulated OFDM system.

It has been noted that for some OFDM parameters combinations, the simulation may get fail for some trials but may succeed in repetitions with the same parameters. It is because the random noise generated in each test differs, and it is possible that there were problems with the frame detector in the OFDM receiver due to certain random noise. Future work is needed to debug this problem and make the frame detector free of error.
Other possible future job is to enhance this simulation program include adding the ability to accept data from input sources in a word size other than 8-bit, adding an option to use another digital modulation techniques instead of M-DPSK as the modulation method.

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