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M-Psk Based OFDM Simulation in Wireless Communication Systems

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Abstract: *Orthogonal frequency division multiplexing (OFDM) is a special case of multicarrier transmission and frequency division multiplexing, where a single data stream is transmitted over several lower rate subcarriers, placed orthogonal to each other. Today it has become the chosen modulation technique for wireless communications. It can provide large data rates with optimum bit error rate and enough robustness to radio channel impairments. In this paper, a complete M-PSK based OFDM simulation is carried out, to analyze the performance of OFDM system in terms of Bit Error Rate (BER), Average Phase Error (APE), Average Root Mean Square (ARMS) values of OFDM signal at the entrance and exit of the channel and Percent error of pixels of the received image. BPSK, QPSK, 16PSK, 256PSK techniques are analyzed in reference to OFDM processing.*

Keywords: *OFDM, BER, PER, PAPR, PIXEL ERROR, PSK*

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is an attractive technology for Wireless Communications which is one of Multi Carrier Modulation (MCM) techniques, offers a considerable high spectral efficiency, multipath delay spread tolerance, immunity to the frequency selective fading channels and power efficiency [1], [2]. As a result, OFDM has been chosen for high data rate communications and has been widely deployed in many wireless communication standards such as Digital Video Broadcasting (DVB), Digital Audio Broadcasting (DAB) and based mobile worldwide interoperability for microwave access (mobile WiMAX) based on OFDM access technology [3].

In a single carrier communication system, the symbol period must be much greater than the delay time in order to avoid inter-symbol interference (ISI) [4]. Since data rate is inversely proportional to symbol period, having long symbol periods means low data rate and communication inefficiency. A multicarrier system, such as Frequency Division Multiplexing (FDM), divides the total available bandwidth in the spectrum into sub-bands for multiple carriers to transmit in parallel [5]. An overall high data rate can be achieved by placing carriers closely in the spectrum. However, inter-carrier interference (ICI) will occur due to lack of spacing to separate the carrier. To avoid inter-carrier interference, guard bands will need to be placed in between any adjacent carriers, which results in lowered data rate.

OFDM (Orthogonal Frequency Division Multiplexing) is a multicarrier digital communication scheme to solve both issues. It combines a large number of low data rate carriers to construct a composite high data rate communication system. Orthogonality gives the carriers a valid reason to be closely spaced, even overlapped, without inter-carrier interference. Low data rate of each carrier implies long symbol periods, which greatly diminishes inter-symbol interference.

Although the idea of OFDM started back in 1966 [6], it has never been widely utilized until the last decade when it “becomes the modem of choice in wireless applications” [7]. It is now interested enough to experiment some insides of OFDM.

The objective of this paper is to demonstrate the concept and feasibility of an OFDM system, and investigate how its performance is changed by varying some of its major parameters. This objective is met by developing a MATLAB program to simulate a basic OFDM system. From the process of this development, the mechanism of an OFDM system can be studied; and complete characteristics of an OFDM system can be explored.

2. System Model

OFDM Transmitter maps the message bits into a sequence of PSK or QAM symbols which will be subsequently converted into N parallel streams. Each of **N** symbols from serial-to-parallel(**S/P**) Conversion is carried out by the different subcarrier.

Let $\mathbf{X_l[k]}$ denote the i'th transmit symbol at the k'th subcarrier, l=0,1,2,…,∞, k=0,1,2,…,N-1.

Due to the S/P conversion the duration of transmission time for N symbols is extended to $\mathbf{NT_S}$, which forms a single OFDM symbol with a length of T_{sym}, (I .e, $T_{sym} = NT_S$). Let $\psi_{l,k}(t)$ denote the *l*'th OFDM signal at the *k*'th subcarrier, which is given as

$$\psi_{l,k}(t) = \begin{cases} e^{j2\pi f_k (t-lT_{sym})}, & 0<t\le T_{sym} \\ 0, & elsewhere \end{cases} \qquad (1)$$

Then the Pass band and Baseband OFDM signals in the continuous-time domain can be expressed respectively as

$$x_l(t) = \mathrm{Re}\left\{\frac{1}{T_{sym}} \sum_{l=0}^{\infty}\left\{ \sum_{k=0}^{N-1} X_l[k]\psi_{l,k}(t)\right\}\right\} \qquad (2)$$

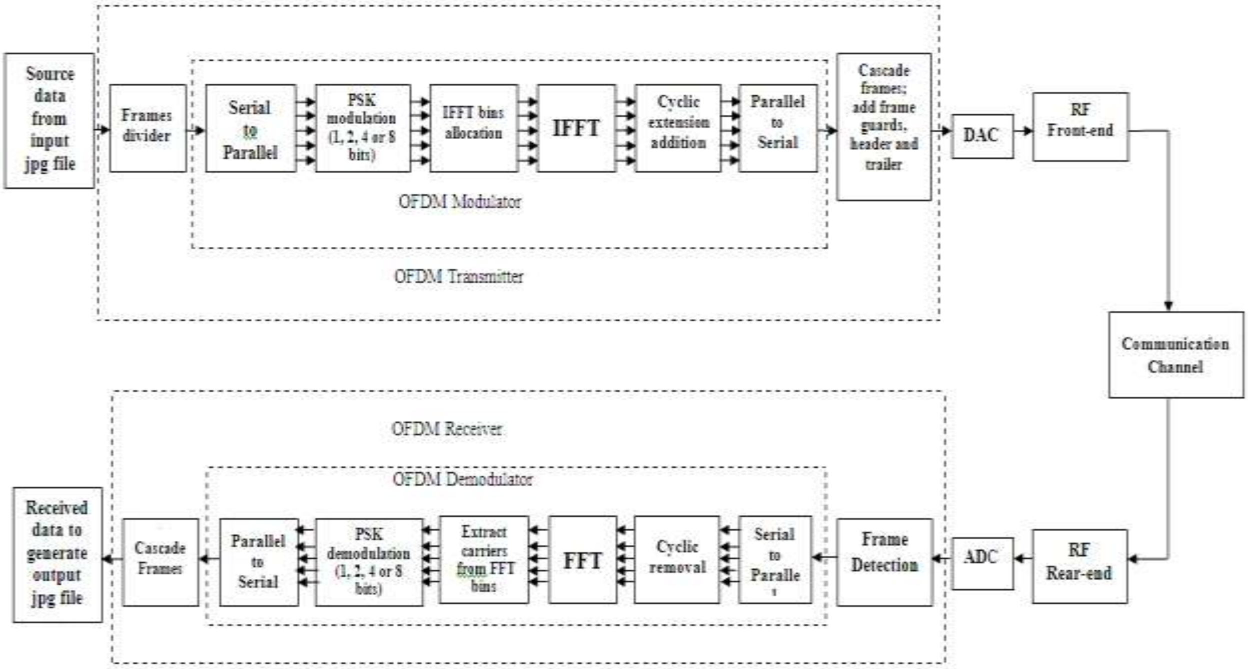

Fig.1. *Block diagram of OFDM system*

And

$$x_l(t) = \sum_{l=0}^{\infty}\sum_{k=0}^{N-1} X_l[k] e^{j2\pi f_k (t-T_{sym})}$$

The continuous-time Baseband OFDM signal in equation (2) can be sampled at $\mathbf{t = lT_{sym} + nTS}$ with $\mathbf{T_S = T_{sym}/N}$ and $\mathbf{f_k = k/T_{sym}}$ to yield the corresponding discrete-time OFDM symbol as

$$x_n[n] = \sum_{k=0}^{N-1} X_l[k] e^{\frac{j2\pi kn}{N}} \qquad for\ n = 0,1,\ldots,N-1 \qquad (3)$$

equation (3) turns out to be the N-point IDFT of **PSK** or **QAM** data symbols $X_l[k]$ and can be computed efficiently by using the IFFT (inverse fast Fourier transform) algorithm.

So consider the received Baseband OFDM symbol $y_l(t) = \sum_{k=0}^{N-1} X_l[k] e^{j2\pi f_k (t-lT_{sym})}$, $\mathbf{lT_{sym} < t \le lT_{sym} + nTs}$, from which the transmitted symbol $\mathbf{X_l[k]}$ can be reconstructed by the orthogonality among the subcarriers as follows…

$$Y_l[k] = \frac{1}{T_{sym}} \int_{-\infty}^{\infty} y_l(t)\, e^{-j2\pi f_k (t-lT_{sym})} dt$$

$$= \frac{1}{T_{sym}} \int_{-\infty}^{\infty} \left\{ \sum_{l=0}^{N-1} X_l[l]\, e^{j2\pi f_k (t-lT_{sym})} \right\} e^{-j2\pi f_k (t-lT_{sym})}\, dt$$

$$= \sum_{i=0}^{N-1} X_l[i] \left\{ \frac{1}{T_{sym}} \int_0^{T_{sym}} e^{j2\pi(f_i - f_k)(t - lT_{sym})} dt \right\} = X_l[k]$$

(4)

Where the effects of the channel and noise are not taken into account .Let $y_l[n]$ be the sample values of the received OFDM symbol $y_l(t)$ at **t=*l*Tsym+nTs**. Then the integration in the modulation process of equation (4) can be represented in the discrete time as follows…

$$Y_l[k] = \sum_{n=0}^{N-1} y_l[n] e^{-j2\pi kn/N}$$

$$= \sum_{n=0}^{N-1} \left\{ \frac{1}{N} \sum_{l=0}^{N-1} X_l[i]\, e^{j2\pi kn/N} \right\} e^{-j2\pi kn/N}$$

$$= \frac{1}{N} \sum_{n=0}^{N-1} \sum_{i=0}^{N-1} [i]\, e^{j2\pi(l-k)n/N} = X_l[k]$$

(5)

equation (5) is the N point DFT of $y_l[n]$ and can be computed efficiently by FFT (Fast Fourier transform) algorithm.

OFDM modulation and demodulation can be illustrated by the black diagram in fig (1).Which shows that the frequency domain symbol **X[k]** modulate the subcarrier with a frequency of **f_k=k/Tsym,** while it can be demodulated by using the orthogonality among the subcarriers in the receiver.

3. OFDM Parameters And Characteristics

The number of carriers in an OFDM system is not only limited by the available spectral bandwidth, but also by the IFFT size (the relationship is described by number of carriers = [(IFFT size/2) – 1] which is determined by the complexity of the system [8]. The more complex (also more costly) the OFDM system is, the higher IFFT size it has; thus a higher number of carriers can be used, and higher data transmission rate achieved.

The key to OFDM is maintaining orthogonality of the carriers. Two sinusoids with frequencies that are integer multiples of a common frequency can satisfy the criterion of orthogonality.

$$\int_0^T \cos(2\pi nft)\cos(2\pi mft)\,dt = 0 (n \neq m)$$

(6)

Where ***n*** and ***m*** are two unequal integers; ***f*** is the fundamental frequency; *T* is the period over which the integration is taken. For OFDM**,** *T* is one symbol period and f set to $\frac{1}{T}$ for optimal effectiveness [9 and 10].

4. Phase Shift Keying

The most popular M-PSK modulation techniques include BPSK, QPSK, 16-PSK and 256-PSK. The M-PSK schemes are usually designed with the number of constellation points being a power of 2.

In PSK, the constellation points chosen are usually positioned with uniform angular spacing around a circle. This gives maximum phase-separation between adjacent points and thus the best immunity to corruption.

4.1 Binary Phase Shift Keying (BPSK)

In binary phase shift keying, the two phases are separated by 180^0. If the sinusoidal carrier has an amplitude A_c and energy per bit $E_b = ½ A_c^2 T_b$, then the transmitted BPSK signal is

$$S_{BPSK}(t) = m(t)\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \theta_c)$$

(7)

It is convenient to generalize m1 and m2 as a binary data signal m(t), which takes on one of two possible pulse shapes.

4.2 Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying has twice the bandwidth efficiency of BPSK, and the phase of the carrier takes on one of four equally spaced values, such as 0, Π/2, Π and 3Π/2, where each value of phase corresponds to a unique pair of message bits.

The QPSK signal may be defined as

$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[2\pi f_c t + (i-1)\frac{\pi}{2}\right]$$

$$\text{for } 0 \le t \le T_b \qquad i = 1,2,3,4$$

(8)

Where T_s is the symbol duration and is equal to twice the bit period.

QPSK signal can be depicted using a two-dimensional constellation diagram with four points i.e., 0, Π/2, Π and 3Π/2 or Π/4, 3Π/4, 5Π/4 and

7Π/4.

The choice of PSK modulation varies the data rate and Bit Error Rate (BER). The higher order of PSK leads to larger symbol size, thus less number of symbols needed to be transmitted, and higher data rate is achieved. But this results in a higher BER, since the range of 0-360^0 degrees of phases will be divided into more sub-regions, and the smaller size of sub-regions is required, thereby received phases have higher chances to be decoded incorrectly. OFDM signals have high peak-to-average ratio, therefore it has a relatively high tolerance of peak power clipping due to transmission limitations.

5. Results and Discussions

Source data for this simulation is taken from an 8-bit grayscale (256 gray levels) Joint photograph Expert Group (*.jpg) based on the user's choice. The image data will then be converted to the symbol size (bits/symbol) determined by the choice of *M*- PSK (BPSK, QPSK, 16-PSK, 256-PSK) from four variations provided by this simulation. The converted data will then be separated into multiple frames by the OFDM transmitter. The OFDM modulator modulates the data frame by frame. Before the exit of the transmitter, the modulated frames of time signal are cascaded together along with frame guards inserted in between as well as a pair of identical headers added to the beginning and end of the data stream. The communication channel is modeled by adding Gaussian white noise and amplitude clipping effect.

The receiver detects the start and end of each frame in the received signal by an envelope detector. Each detected frame of time signal is then demodulated into useful data. The modulated data is then converted back to 8-bit word size data used for generating an output image file of the simulation.

Input:

1. Source data file Name: **"input.jpg"**
2. IFFT Size: **256**
3. Number of Carriers : **64**
4. Digital Modulation method: **QPSK**
5. Signal peak power clipping in dB: **5**
6. Signal-to-Noise Ratio in dB: **20**

Input data file:

Fig.2. *Input data file*

Output:

1. Peak to Average Power Ratio at entrance of channel is: 13.966231 dB
2. Peak to Average Power Ratio at exit of channel is: 10.216890 dB
3. OFDM data transmitted in 23.758930 seconds
4. OFDM data received in 37.976951 seconds
5. Data loss in this communication = 0.153333% (2944 out of 1920000)
6. Total number of errors = 5555 (out of 1917056)
7. Bit Error Rate (BER) = 0.289767%
8. Average Phase Error (APE) = 3.742182 (degree)
9. Percent error of pixels of the received image = 0.515000%

The simulation results are shown in the following Figures 3(a) – 3(f). The constellation diagram of the received phases in shown Figure (4).

Error calculations are performed at the end of the program. Representative plots are shown throughout the execution of this simulation.

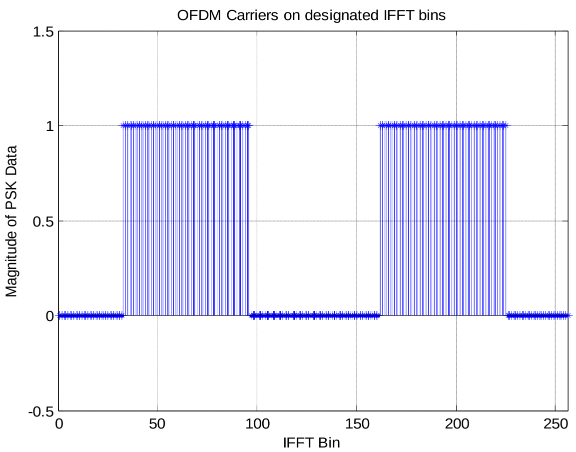

Fig. 3(a). *OFDM carriers on designated IFFT bins*

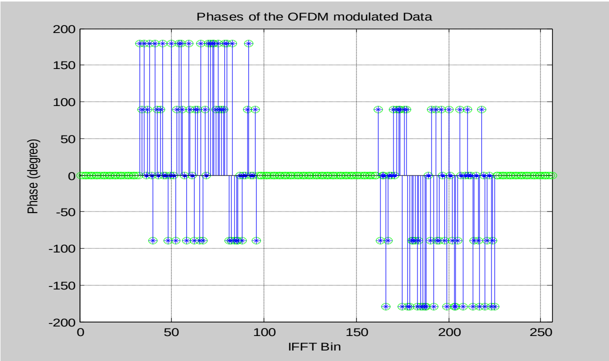

Fig. 3(b). *Phases of the OFDM modulated Data*

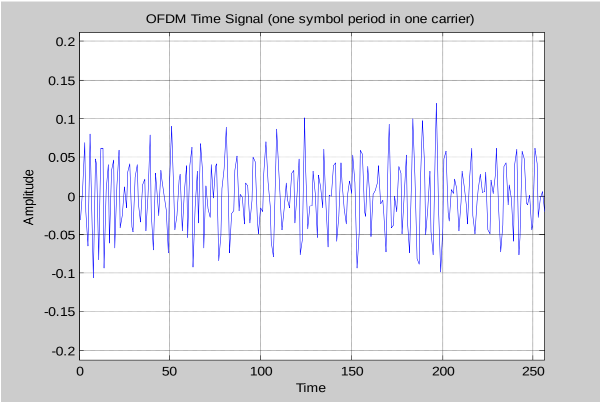

Fig. 3(c). *OFDM Time signal one symbol period in one carrier*

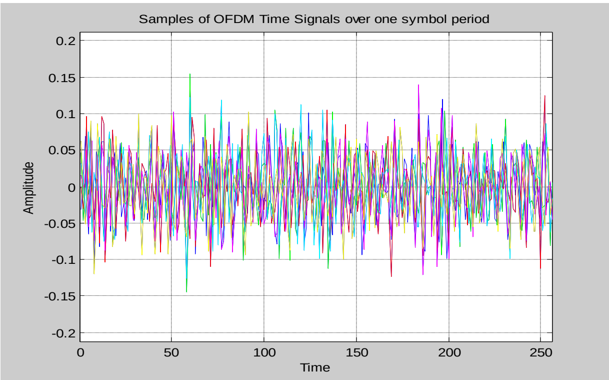

Fig.3(d). *Samples of OFDM Time Signals over one symbol period*

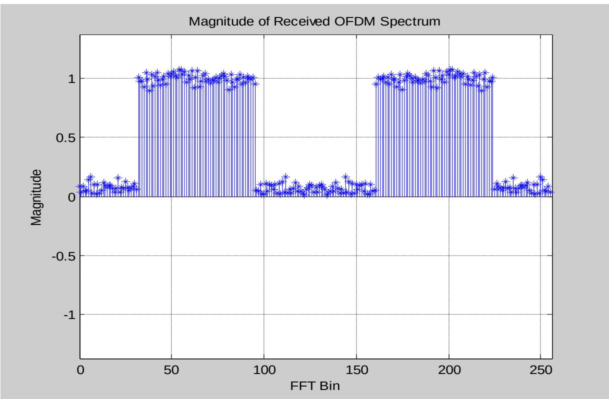

Fig. 3(e). *Magnitude of Received OFDM Spectrum*

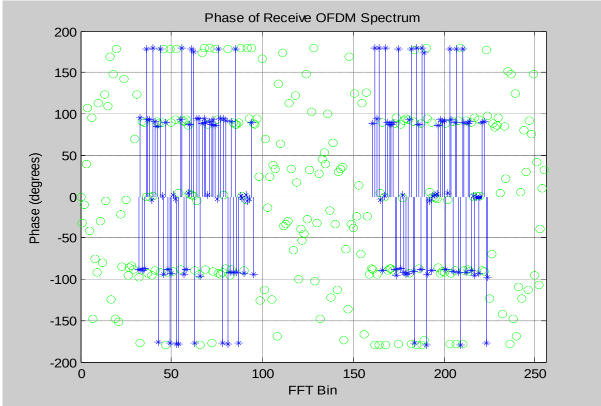

Fig. 3(f). *Phase of Received OFDM spectrum*

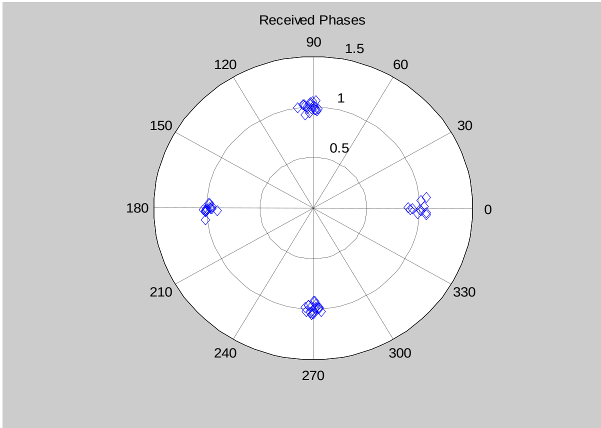

Fig. 4. *Received Phases*

Figure (5) shows the relationship between Bit Error Rate (BER) and Signal to Noise Ratio the (SNR) for all four *M*-PSK methods.

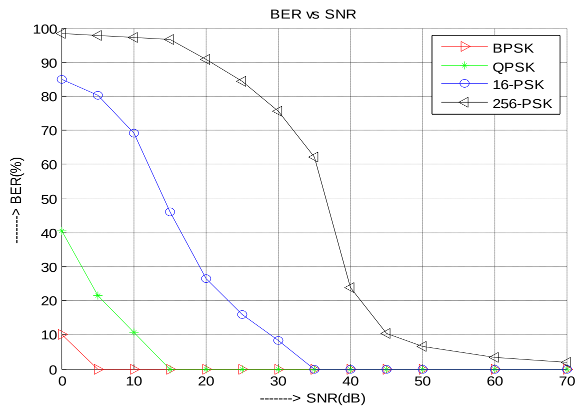

Fig. 5. *BER vs SNR*

SNR is inversely proportional to error rates. To demonstrate this, as an experiment, a different set of parameters are used. As expected, higher order PSK requires a larger SNR to minimize BER.

Figure (6) shows the relationship between Pixel Error and Signal to Noise Ratio the (SNR) for all four *M*-PSK methods.

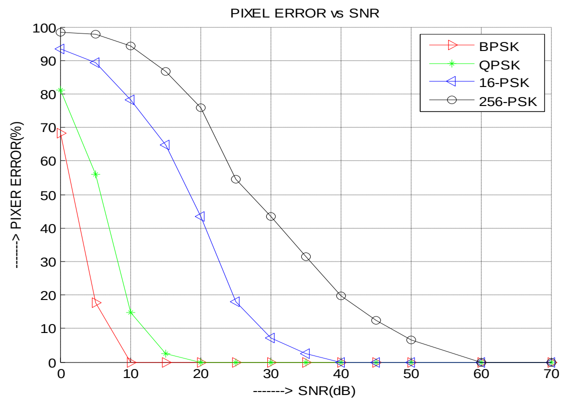

Fig. 6. *Pixel Error vs SNR*

256- PSK and 16-PSK modulation schemes require a relatively large SNR to transmit data with an acceptable Percentage Pixel Error as shown in Figure (6).

The received data file is shown in Figure (7).

Fig. 7. *Received data file*

6. Conclusion

M-PSK based OFDM system is simulated some of the challenges in developing this OFDM simulation program were carefully matching steps in modulator and demodulator, keeping track of data format and data size throughout all the processes of the whole simulation, designing an appropriate frame detector for the receiver, and debugging the MATLAB codes. It was noted that for some combinations of OFDM parameters, the simulation may fail for some trials but may succeed for repeated trails with the same parameters. It is because the random noise generated on every trial differs, and trouble may have been caused for the frame detector in the OFDM receiver due to certain random noise. Future work is required to debug this issue and make the frame detector free of error and also adding an option to use **QAM** (Quadrature amplitude modulation) instead of **M-PSK** as the modulation method.

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