EEE 310 Project

# OFDM Simulation Using MATLAB

A comparison between various digital modulation techniques.


Prepared By

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# Introduction

OFDM (Orthogonal Frequency Division Multiplexing) is an advanced form of FDM (Frequency Division Multiplexing). Data rate in OFDM is very high. As a result, OFDM is used in 4th Generation Wireless communications like LTE, LTE-A, WiMAX.

In FDM we use have different frequency band for each user, and each frequency band is separated by guard band to solve the ISI problem. But this guard band creates a delay.

But in OFDM all the carriers are orthogonal (FFT of rect is sinc). Carriers are located at a fixed distance in frequency domain. The carriers are located such that one carrier has peak at the null point of another carrier. This phenomenon is known as orthogonality and requires no guard band.

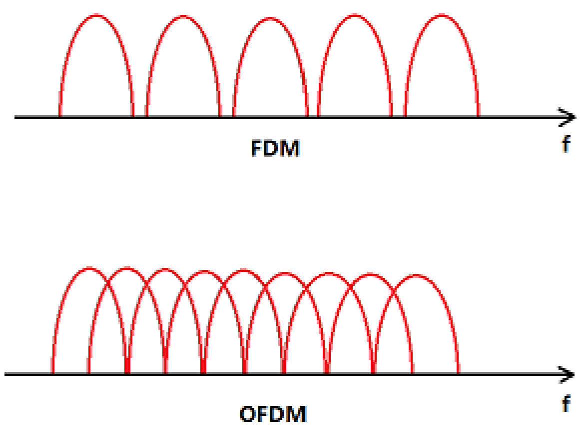



*Figure 1: Comparison betweeen OFDM and FDM*

One of the main hindrances in having higher data rate is multipath fading. In this problem, Reflections from near-by objects (e.g. ground, buildings, trees, etc) can interfere with the signal received signal. As a result, there may be a destructive interference at the receiver and may result in cancellation of certain frequencies at the Receiver. Multipath fading also creates ISI (Inter symbol Interference), which is the interference of all the reflected signals at the receiver end. This resultant signal has a longer spread in time domain. In air medium, this problem in unavoidable. Which is a tradeoff for wireless communication system.

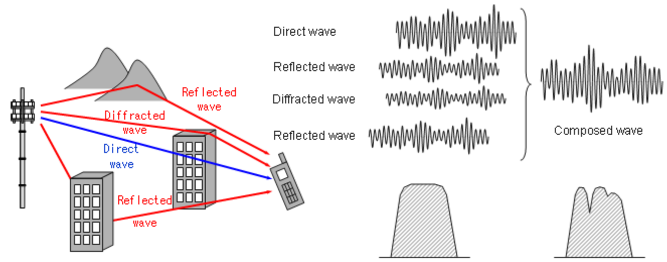



*Figure 2: Multipath Fading*

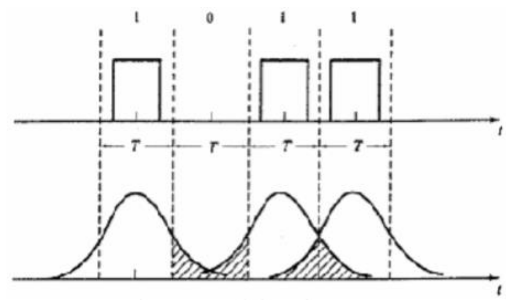



*Figure 3: Inter Symbol Interference*

To solve Multipath fading, one solution is slowing data transmission rate. If we have long symbol interval there will be no ISI. But nowadays, transmission rate demand is increasing.

The solution to this problem is to divide data and create multiple data streams. As a result, each data stream duration is increased also using multiple subcarriers, data rate increases.

Orthogonality of signal is maintained during the transmission

# OFDM

In digital communications, information is expressed in the form of bits. The term symbol refers to a collection, in various sizes, of bits. OFDM data are generated by taking symbols in the spectral space using M-PSK, QAM, etc., and convert the spectra to time domain by taking the Inverse Discrete Fourier Transform (IDFT). Since Inverse Fast Fourier Transform (IFFT) is more cost effective to implement, it is usually used instead. Once the OFDM data are modulated to time signal, all carriers transmit in parallel to fully occupy the available frequency bandwidth. Long symbol periods diminish the probability of having inter-symbol interference, but could not eliminate it. To make ISI nearly eliminated, a cyclic extension (or cyclic prefix) is added to each symbol period. An exact copy of a fraction of the cycle, typically 25% of the cycle, taken from the end is added to the front.

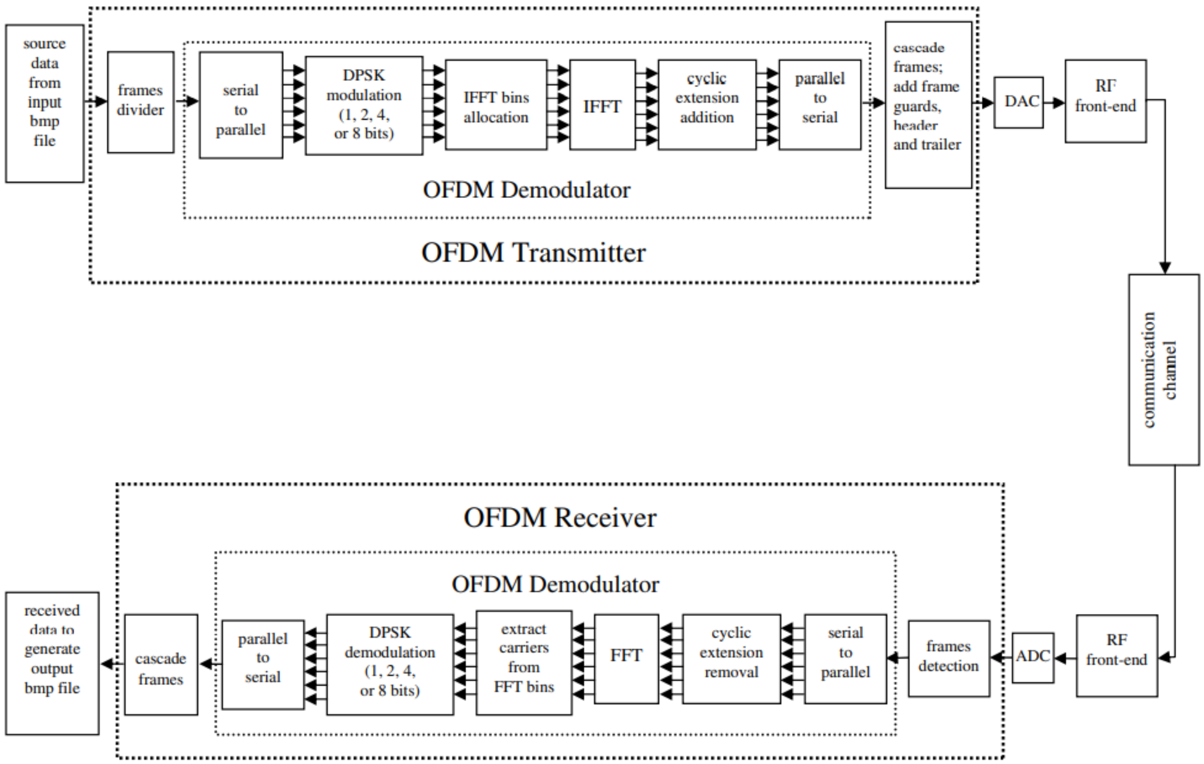



*Figure 4: OFDM Block Diagram*

## Transmission

In the transmission block we have OFDM modulator as well as multiplexing part.

## Input

Source data for this simulation is taken from $512 \times 512$RGB image file based on the user's choice. Resultant matrix has a shape of $512 \times 512 \times 3$. Then the image data is converted into binary sequence of $[1010110110001 \ldots \ldots \ldots]$.

Matrix size:

Before binary conversion: $786432 \times 1$

After binary conversion: $786432 \times 8 = 6291456 \times 1$

## Serial to Parallel

The converted data will then be separated into multiple frames by the OFDM transmitter. The Binary sequence is mapped into frame size of $64$ and is divided into $104854$ frames. i.e., 1D $6291456 \times 1$ sequence is transformed into $60 \times 104854$ 2D Matrix. Due to mis-match in size, some zeros are added in the sequence

## Digital Modulation

The data to be transmitted on each carrier is then differential encoded with previous symbols, then mapped into a Phase Shift Keying (PSK) format. Since differential encoding requires an initial phase reference an extra symbol is added at the start for this purpose. The data on each symbol is then mapped to a phase angle based on the modulation method. For example, for QPSK the phase angles used are 0, 90, 180, and 270 degrees. The use of phase shift keying produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading.

## BPSK

Binary Phase-shift keying (BPSK) is a digital modulation scheme that conveys data by changing, or modulating, two different phase s of a reference signal (the carrier wave). 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. They are positioned on a circle so that they can all be transmitted with the same energy. In this way, the moduli of the complex numbers they represent will be the same and thus so will the amplitudes needed for the cosine and sine waves.

### QPSK

Quadrature Phase Shift Keying (QPSK) is a form of Phase Shift Keying in which two bits are modulated at once, selecting one of four possible carrier phase shifts (0, 90, 180, or 270 degrees). QPSK allows the signal to carry twice as much information as ordinary PSK using the same bandwidth.

### QAM

Quadrature amplitude modulation (QAM) is the name of a family of digital modulation methods and a related family of analog modulation methods widely used in modern telecommunications to transmit information. It is a form of modulation that is a combination of phase modulation and amplitude modulation. The QAM scheme represents bits as points in a quadrant grid know as a constellation map.

### 16QAM

16QAM is a modulation technique in which the carrier can exist in one of sixteen different states. As such, each state can represent four bits – 0000 through to 1111, per symbol change.

### 32QAM

32QAM is a modulation technique in which the carrier can exist in one of thirty-two different states. As such, each state can represent four bits – 00000 through to 11111, per symbol change.

### Pilot Value

Then we add 4 pilot values in the sequences. The number of pilots in the OFDM symbol describes, how many carriers are used to transmit known information (i.e., pilots). These values will be known to the receiver end for necessary channel estimation. As a result, out matrix size increases to $64 \times 104854$ 2D Matrix. For QPSK, we chose $3 + 3i$.

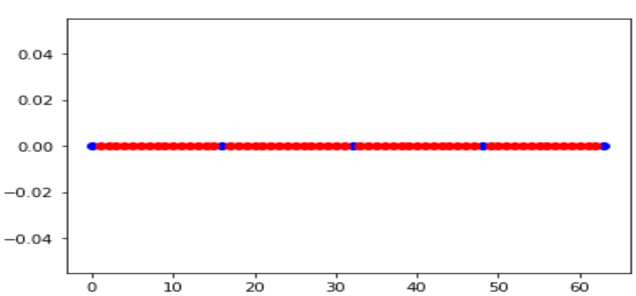



*Figure 5: Red indicates data carrier and blue indicates pilot carrier in the carrier frequency.*

### IFFT

The OFDM modulator modulates the data frame by frame. In each frame we have bit stream. IFFT is performed on this bit stream to convert the data into time domain. As a result, a narrow baseband signal is generated due to IFFT. If $d_i$ is the digital modulated symbol, then we have

$$s(t) = \sum_{i=0}^{N-1} d_i e^{\frac{j2\pi i}{N} t}$$

IFFT the data sequences into 64 discrete time signal values. The first four signals and their corresponding frequency domain is shown below

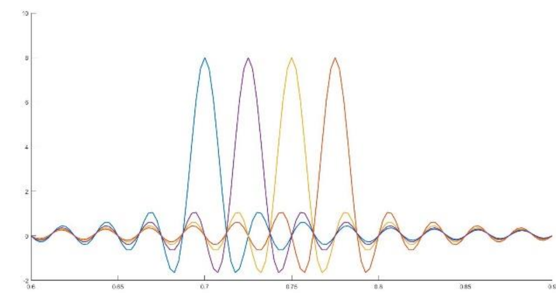


*Figure 6: Frequency domain of four carrier*

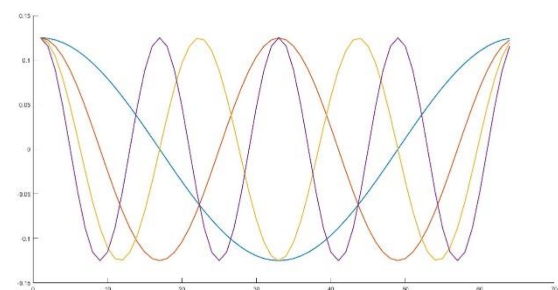


*Figure 7: Corresponding time domain*

### Cyclic Prefix

The length of the cyclic prefix (CP) denotes the number of samples that are copied from the end of the modulated block to the beginning, to yield a cyclic extension of the block. Cyclic prefix acts as a frame guard and Reduces Inter Symbol Interference. It isolates different OFDM blocks from each other when the wireless channel contains multiple paths.

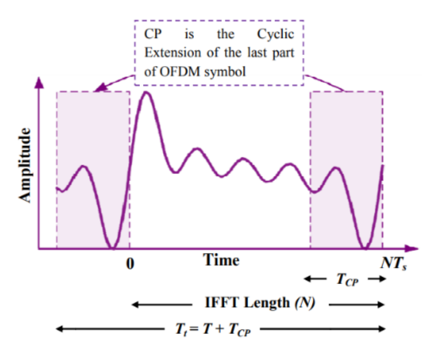



*Figure 8: Addition of Cyclic Prefix*

### Parallel to Serial

Before the exit from the transmitter, the modulated frames of time signal are cascaded together. As a result, the converted parallel data again converts into serial time-domain baseband data.

### Channel

Now, the signal is sent to the antenna and sent over the air to the receiver. In between both antennas, there is the wireless channel. We model this channel as a static multipath channel with impulse response channel Response. Hence, the signal at the receive antenna is the convolution of the transmit signal with the channel response. Additionally, we add some noise to the signal according to the given SNR value:

### Multipath Fading

If $s(t)$ is the transmitted signal and $h(t)$ is the multipath fading channel impulse response. Then the received signal is the convolution,

$$r(t) = s(t) \star h(t)$$

### Noise

And finally, if we add AWGN then our received signal will be,

$$r(t) = s(t) \star h(t) + w(t)$$

where, $w(t)$ is our White Gaussian Noise.

### Reception

The received signal is a distorted and noisy version of the transmitted analog OFDM signal. The receiver detects the start and end of each frame in the received signal by an envelope detector.

### Serial to Parallel

In this section, serial data are again shifted to parallel data stream.

### Remove cyclic prefix

Now, at the receiver the CP is removed from the signal and a window of 64 samples is extracted from the received signal.

### FFT

Afterwards, the signal is transformed back to the frequency domain, in order to have the received value on each subcarrier available.

### Channel Estimation

From the received information at the pilot subcarriers, the receiver can estimate the effect of the wireless channel onto this subcarrier (because it knows what was transmitted and what was received). Hence, the receiver gains information about the wireless channel at the pilot carriers. Channel Response in frequency domain,

$$H(\omega) = \frac{P(\omega)}{X(\omega)}$$

Here $P$ denotes received Pilot value and X denotes Pilot value. Finally, we have our channel estimation output, $Y(\omega) = H^{-1} \times R(\omega)$, Here $R$ is the received signal.

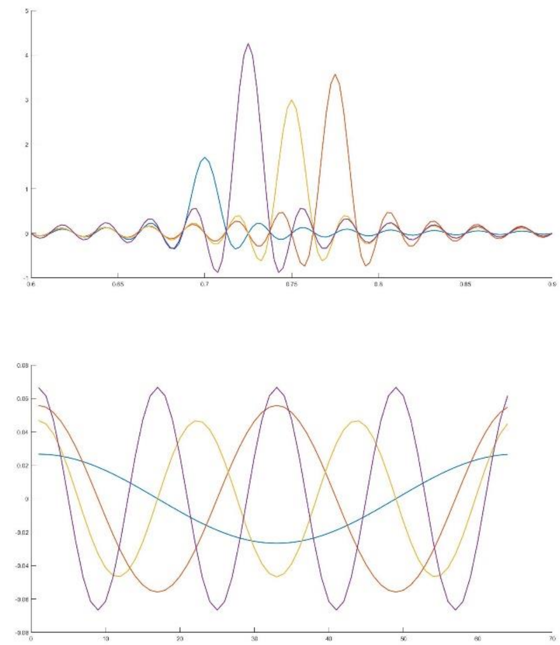


*Figure 9: Corresponding Signal in the demodulation blocl*

### Digital Demodulation

Each detected frame of time signal is then demodulated from symbol to bits.

### Parallel to Serial

Finally, the blocks are shifted from parallel blocks to serial binary streams.

### Output

The modulated data is then converted back to 8-bit word size data used for generating an output image file of the simulation

## Experimental Data and Software:

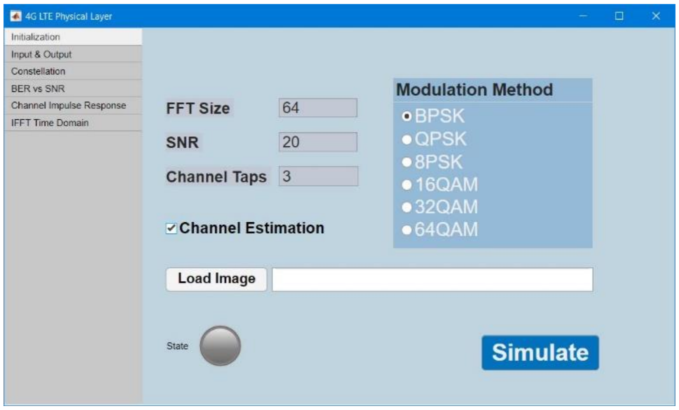
Input image size = $512 \times 512$

FFT/IFFT size = 64

Channel Taps=8

SNR= 20 [Gradually changed]

Channel Estimation Method= Least Square




# Bit Error Rate

Demodulated data is compared to the original baseband data to find the total number of errors. Dividing the total number of errors by total number of demodulated symbols, the bit-error-rate (BER) is found.

$$BER = \frac{Total\ number\ of\ error}{Total\ number\ of\ deodulated\ symbol}$$

# Result and Discussion

*Figure 10: (a)Transmitted Image (b) BPSK (c) 8PSK (d)QPSK (e)16QAM For SNR 5dB*

We have calculated the BER for all the modulation schemes used in this project. Although BER is showing higher value in the table, but looking at the output image, we can see that the images can be identified. This is because decoded pixel may have changed its value by a small number which is undetected to human eye. But this incident is counted as an error.

Table 1: BER Value wrt Modulation Method vs SNR

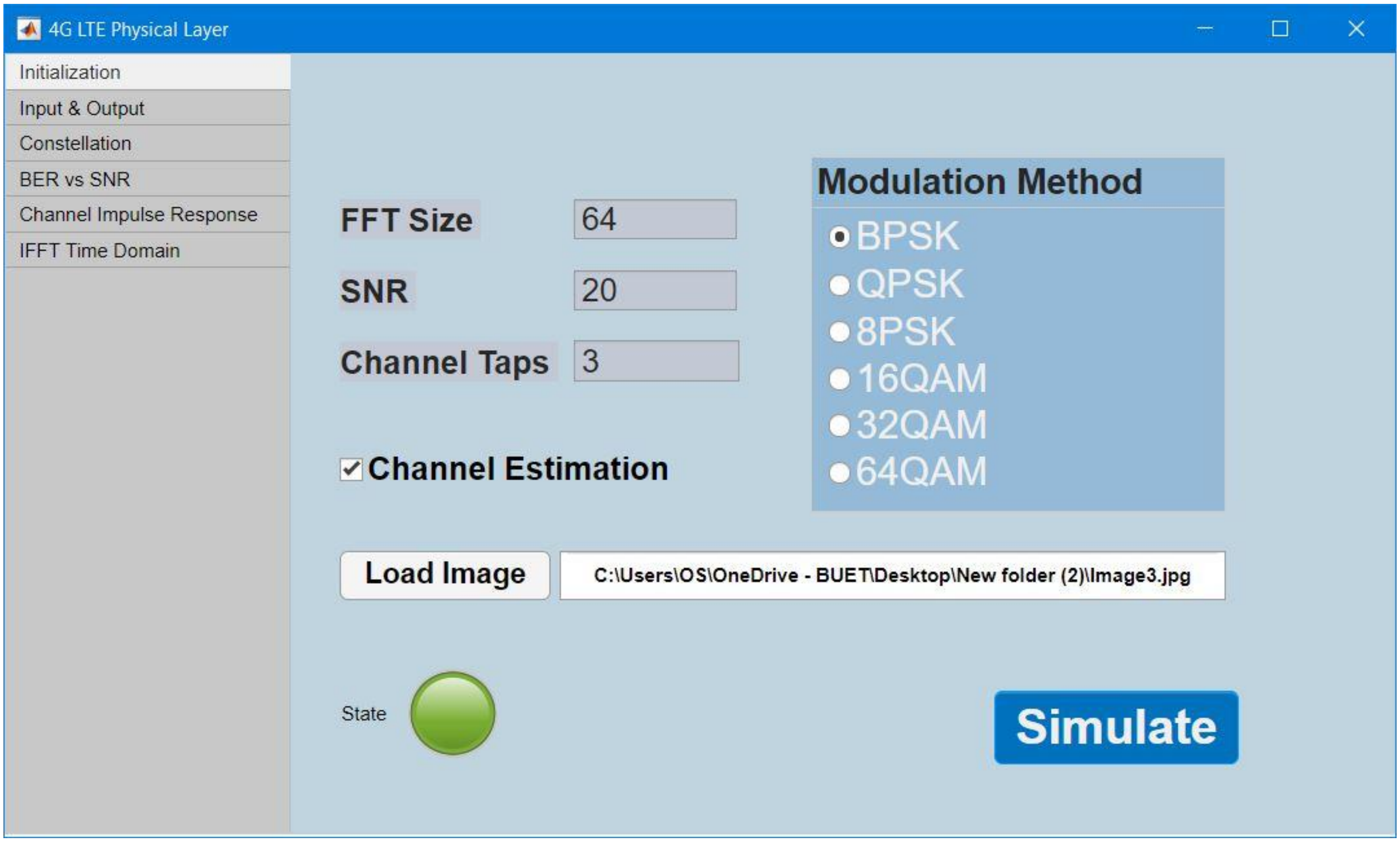
| Modulation | SNR 0dB | SNR 5 dB | SNR 10 dB |
|---|---|---|---|
| **BPSK** | 0.1513 | 0.0626 | 0.0154 |
| **QPSK** | 0.2568 | 0.1553 | 0.0914 |
| **8PSK** | 0.3688 | 0.2975 | 0.2364 |
| **16QAM** | 0.3732 | 0.3358 | 0.3070 |
| **32QAM** | 0.4315 | 0.3948 | 0.3802 |
| **64QAM** | 0.4098 | 0.3808 | 0.3581 |

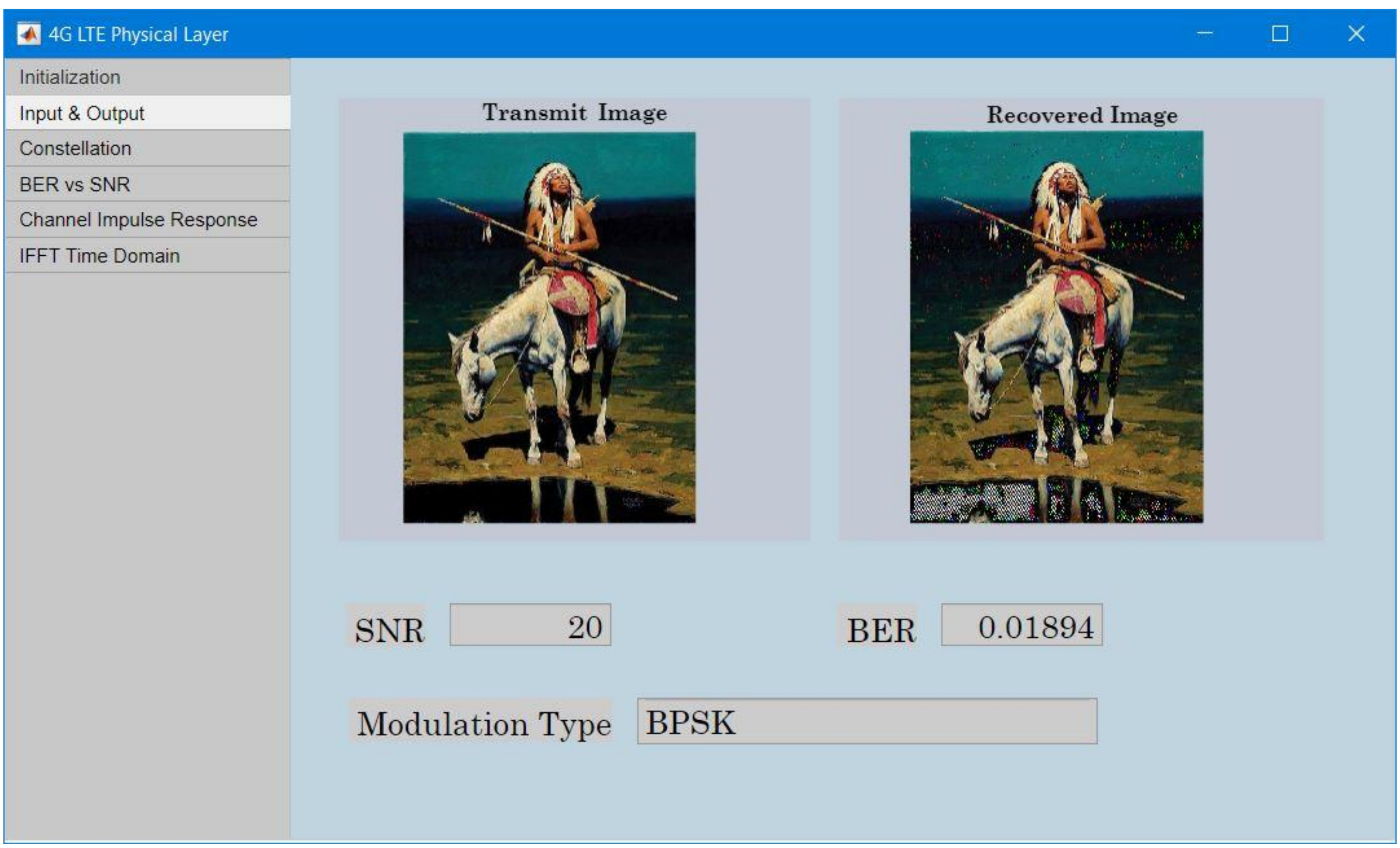
In fact, when toggling between the original and received image in this case, it's obvious that the RGB levels on most of the pixels did change, but the relatively contents are still somewhat intact. A balanced trade-off between BER-tolerance and desire of data rate needs to be found for the type of data to be transmitted using OFDM.

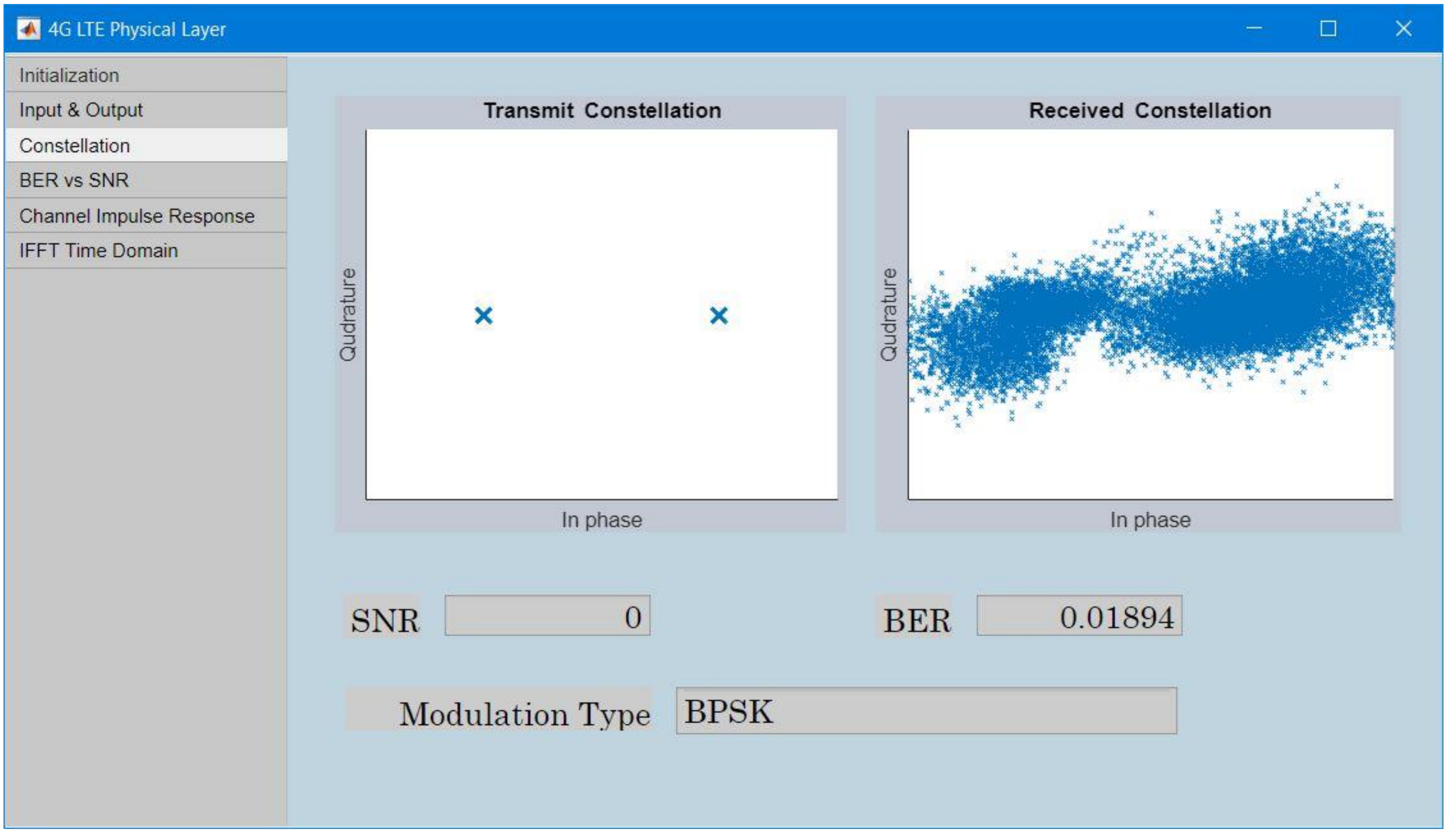
This means that OFDM can be a very effective data transmission method. But, depending on the modulation technique used, the results may vary. When looking at a side-by-side comparison of an image using BPSK, 8PSK, QPSK, and 16QAM, the differences in each method become more apparent. We can see that for the same SNR value various demodulation techniques produces results of varying degrees of quality. The quality differences become more obvious when looking at the reflection in the water. We can see that the first image is very grainy and noisy, the second image looks a little better but there are still some noises present. In the fifth image, the overall quality is good, but we still see some noise in the reflection in the water. Although a little noisy, we can see that the third image provides the most faithful reconstruction oi the original image.

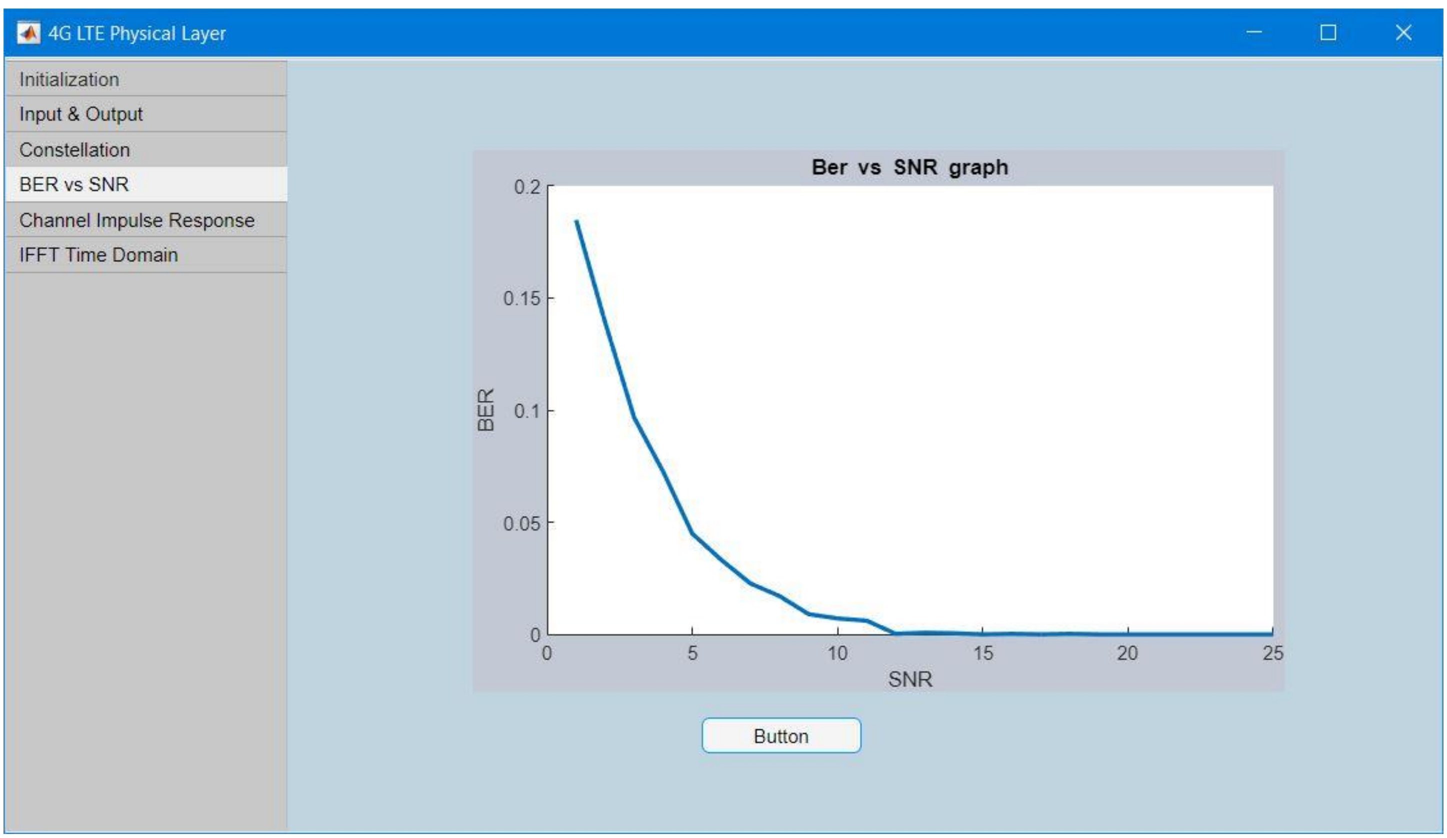
Looking at the table, we see that for any level of noise, BPSK has the least BER while QPSK, 8PSK, 16QAM, 32QAM and 64QAM produce gradually higher BER. We can also see that for 32QAM and 64QAM, the BER is quite close and 64QAM performs slightly better.

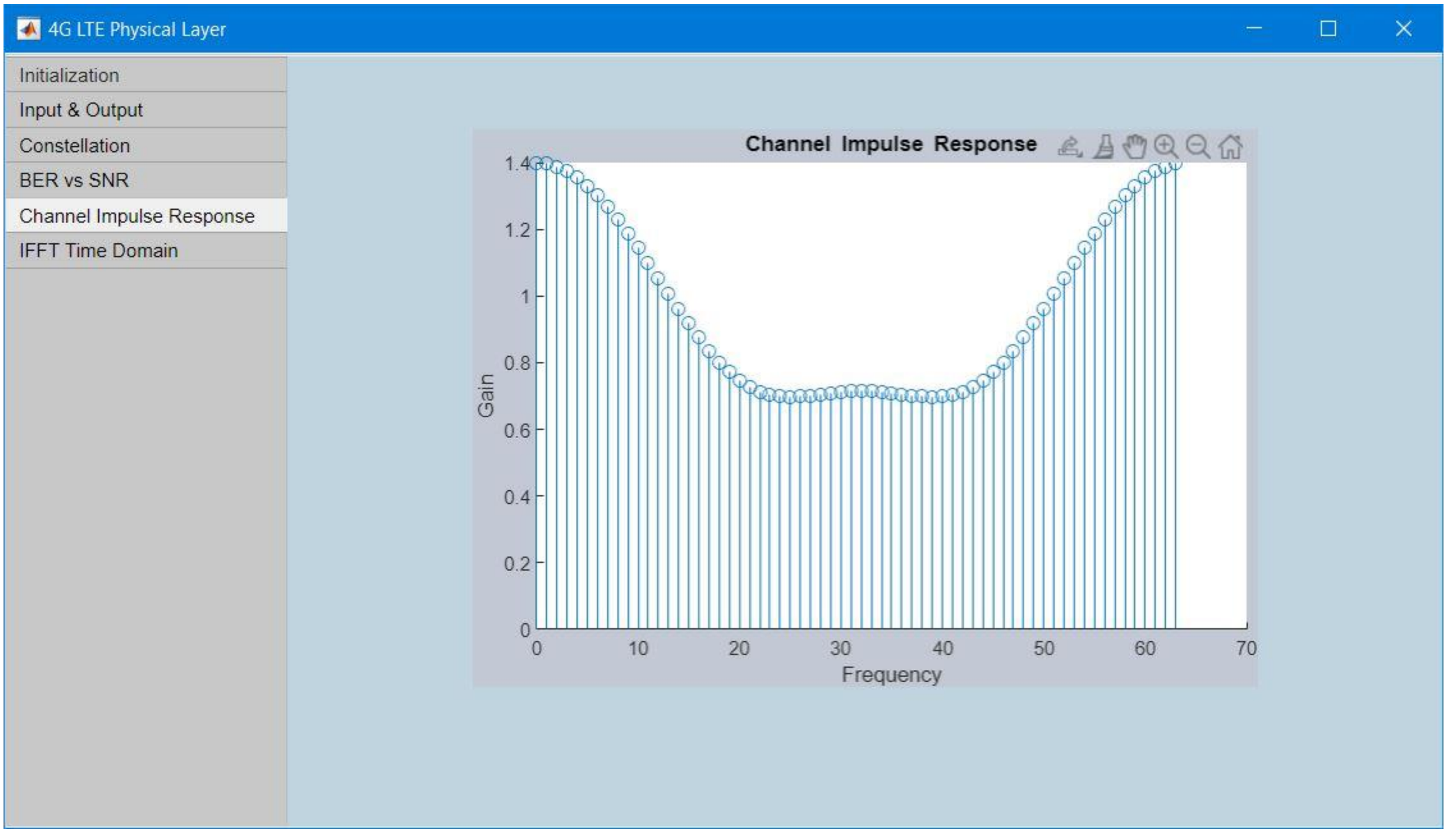
# Software Presentation:




4G LTE Physical Layer
Initialization
Input & Output
Constellation
BER vs SNR
Channel Impulse Response
IFFT Time Domain
Transmit Constellation
Received Constellation
Qudrature
In phase
SNR
0
BER
0.01894
Modulation Type
BPSK


4G LTE Physical Layer
Initialization
Input & Output
Constellation
BER vs SNR
Channel Impulse Response
IFFT Time Domain
Ber vs SNR graph
BER
SNR
Button


4G LTE Physical Layer
Initialization
Input & Output
Constellation
BER vs SNR
Channel Impulse Response
IFFT Time Domain
Channel Impulse Response
Gain
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0.8
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1.2
1.4
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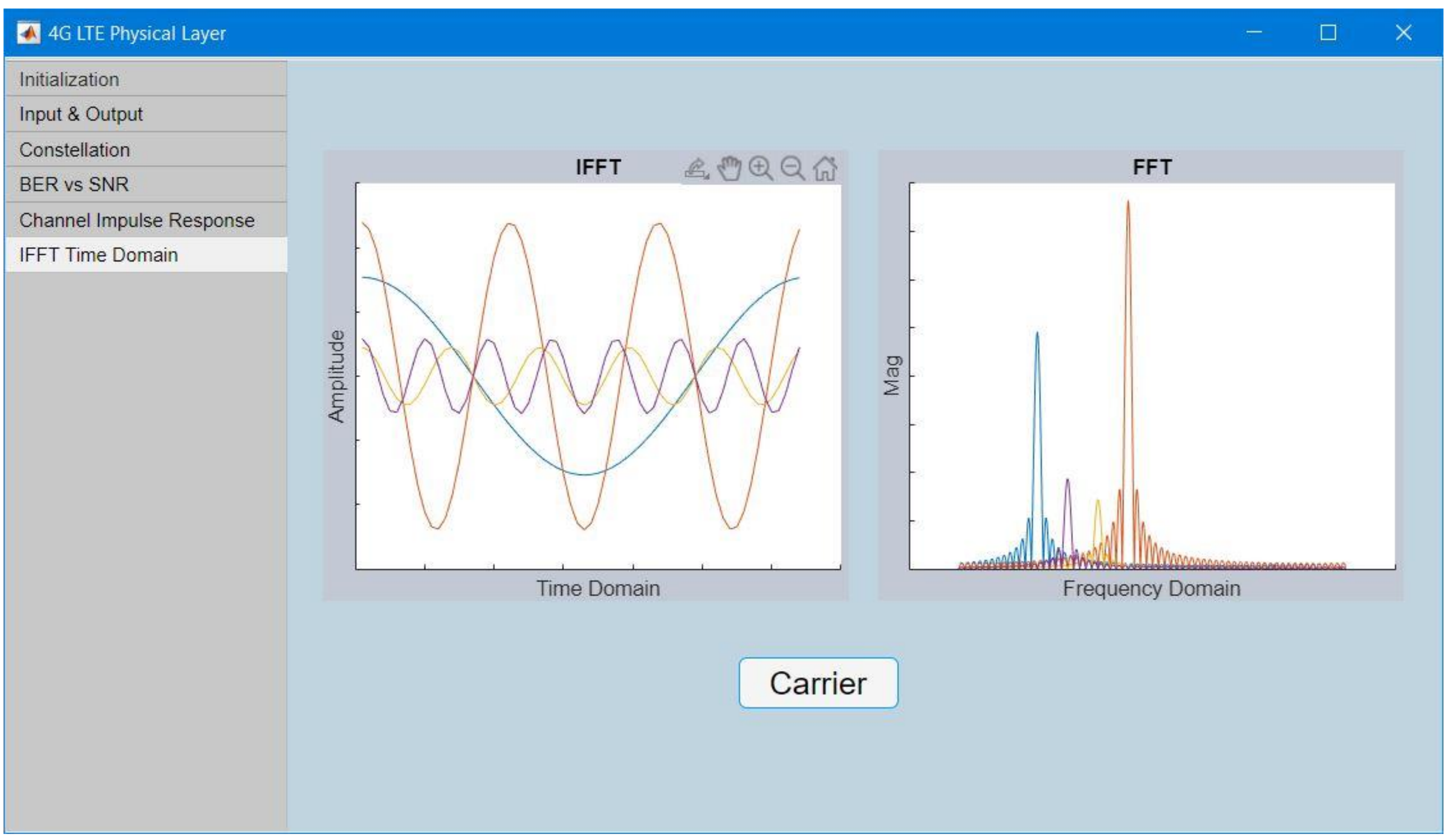
60
70


4G LTE Physical Layer
Initialization
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IFFT
Amplitude
Time Domain
FFT
Mag
Frequency Domain
Carrier