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Implementation of Channel Coding in Orthogonal Frequency Division Multiplexing (OFDM) Systems

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Abstract

The role of channel coding in conjunction with frequency and time interleaving is to provide a link between bits transmitted on separated carriers to be reconstructed in the receiver. Orthogonal Frequency Division Multiplexing (OFDM) has been proving throughout the world as a veritable tool in achieving the high data rate necessary for data demanding applications. The structure of OFDM systems makes channel coding more effective in confronting fading channels. In this paper, we analyzed OFDM system and its effects in channel coding. The bit error ratio (BER) performance of the above systems is carried out with emphasis on the modulation scheme and number of carriers. The results show that additional symbols across time frequency increases the rate of transmission and bandwidth without changing the type of modulation employed.

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Introduction:

The telecommunication industries are now commercially driven by ever more demanding consumers who are ready for seamless communication from their homes to cars, to their office, or even for outdoor activities. Therefore, with the increase demand it became very imperative to transmit information wirelessly, quickly and accurately. Thus, communications engineer combined technologies suitable for high rate transmission with forward error correction (FEC) techniques.

Orthogonal Frequency Division Multiplexing (OFDM) is simply defined as a form of multi-carrier modulation where the carrier spacing is carefully selected so that each sub carrier is orthogonal to the other sub carriers, and their product becomes zero. That is, if you take two signals multiply them together and if their integral over an interval is zero, then two signals are orthogonal in that interval (Proakis, 2017).

Orthogonality can be achieved by carefully selecting carrier spacing, such as letting the carrier spacing be equal to the reciprocal of the useful symbol period. As the sub carriers are orthogonal, the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. This results in no interference between the carriers, allowing them to be spaced and close as theoretically possible. In a conventional serial data system, the symbols are transmitted sequentially, one by one, with the frequency spectrum of each data symbol allowed to occupy the entire available bandwidth. A high rate data transmission supposes very short symbol duration, transmitting at a large spectrum of the modulation symbol. Because of this occurrence, there are good chances that the frequency selective channel response will be affected in a very distinctive manner at different spectral components of the data symbol, hence the need to introduce the ISI, (Salzberg, 2018).

The same phenomenon regarded in the time domain consists of smearing and spreading of information symbols such that the energy from one symbol interfering with the energy of the next ones and the received signal has a high probability of being incorrectly interpreted.

Intuitively, one can assume that the frequency selectivity of the channel can be mitigated instead of transmitting a single high rate data stream, we transmit the data simultaneously on several narrow-band sub-channels (with a different carrier corresponding to each sub-channel) on which the frequency response of the channel looks “flat”. Hence, for a given overall data rate, increasing the number of carriers reduces the data rate that each individual carrier must convey, therefore lengthening the symbol duration on each subcarrier.

The concept of using parallel data transmission by means of frequency division multiplexing (FDM) was published in mid 60’s. A U.S. patent was filled and issued in January 1970. The idea was to use parallel data streams and FDM with overlapping sub channels to avoid the use of high-speed equalization and to combat impulsive noise and multipath distortion as well as to fully use the available bandwidth. The initial applications were in the military communications. Weinstein and Ebert applied the discrete Fourier transform (DFT) to parallel data transmission system as part of the modulation and demodulation process. In the 1980s, OFDM has been studied for high speed modems, digital mobile communications and high-density recording (Chang and Gibby, 2018).

In 1990s, OFDM was exploited for wideband data communications over mobile radio Frequency Modulation (FM) channels, wireless Local Area Network (LAN), wireless multimedia communication, High-Bit-Rate Digital Subscriber Lines (HDSL), Asymmetric Digital Subscriber Lines (ADSL), Very High Speed Digital Subscriber Lines (VHDSL), Digital Audio Broadcasting (DAB) and other terrestrial broadcasting. In a classical parallel data system, the total signal frequency band is divided into N non overlapping frequency sub-channels. Each sub-channel is modulated with a separate symbol and then the N sub-channels are frequency-multiplexed. It seems good to avoid spectral overlap of channels to eliminate inter-channel interference. However, this leads to inefficient use of the available spectrum. To cope with the inefficiency, the ideas proposed in the mid-1960s were to use parallel data and FDM with overlapping Sub-channels, in which, each carrying a signaling rate b is spaced b apart in frequency to avoid the use of high-speed equalization and to combat impulsive noise and multipath distortion, as well as to fully use the available bandwidth (Chang and Gibby, 2018).

Propagation Characteristics of Mobile Radio Channel

In an ideal radio channel, the received signal would consist of only a single direct path signal which would provide perfect reconstruction of the transmitted signal at receiver. However, in a real channel, the signal is modified during transmission in the channel. The received signal consists of a combination of attenuated, reflected, refracted, and diffracted replicas of the transmitted signal. The channel adds noise to the signal and causes a shift in the carrier frequency when the transmitter or receiver is moving. This phenomenon is termed as Doppler Effect. Understanding of this effect on the signal is important because the performance of a radio system is dependent on the radio channel characteristics.

Attenuation; Attenuation is the drop in the signal power when transmitting signal from one point to another. It can be caused by transmission path length, obstructions in the signal path, and multipath effects. Any object which obstructs the line of sight of signal from the transmitter to the receiver can cause attenuation. Shadowing of the signal can occur whenever there is an obstruction between the transmitter and receiver. Attenuation is generally caused by buildings and hills.

Radio signals diffract off the boundaries of obstructions, thus preventing total shadowing of the signals behind hills and buildings. However, the amount of diffraction is dependent on the radio frequency used with low frequencies diffracting more than high frequency signals. Thus high frequency signals especially Ultra High Frequencies (UHF) and microwave signals require line of sight for adequate signal strength, (Hirosaki, 2019). To overcome the problem of shadowing, transmitters are usually elevated as high as possible to minimize the number of obstructions.

Multipath Effects

a. Rayleigh fading: In a radio link, the radio frequency (RF) signal from the transmitter may be reflected by objects such as hills, buildings, or vehicles. This gives rise to multiple transmission paths at the receiver. The relative phase of multiple reflected signals can cause constructive or destructive interference at the receiver. This is experienced over very short distances (typically at half wavelength distances), thus is given the term fast fading. These variations can vary from 10-30dB over a short distance.

Frequency Selective Fading: In any radio transmission, the channel spectral response is not flat. It has dips or fades in response due to reflections causing cancellation of certain frequencies at the receiver. Reflections off near-by objects (e.g. ground, buildings, trees, etc) can lead to multipath signals of similar signal power. This can result in deep nulls in the received signal power due to destructive interference.

For narrow bandwidth transmissions if the null in the frequency response occurs at the transmission frequency, then the entire signal can be lost. This can be partly overcome in two ways. By transmitting a wide bandwidth signal or spread spectrum as Code Division Multiple Access (CDMA), thus, any dips in the spectrum will only result in a small loss of signal power rather than a complete loss. Another method is to split the transmission up into many small bandwidth carriers as it is done in a coded OFDM/OFDM transmission, (Tourtier, *et al*., 2017). The original signal is spread over a wide bandwidth, and any nulls in the spectrum are unlikely to occur at all the carrier frequencies. This will result in only some of the carriers being lost, rather than the entire signal. The information in the lost carriers can be recovered provided enough FEC is sent.

Delay Spread: The received radio signal from a transmitter consists of typically a direct signal, plus reflections from object such as buildings, mountains and other structures. The reflected signals arrive at a later time than the direct signal because of the extra path length, giving rise to a slightly different arrival time of the transmitted pulse, thus spreading the received energy. Delay spread is the time spread between the arrival of the first and last multipath signal seen by the receiver.

In a digital system, the delay spread can lead to inter-symbol interference. This is due to the delayed multipath signal overlapping with the following symbols. This can cause significant errors in high bit rate systems, especially when using time division multiplexing (TDMA).

Doppler Shift: When a wave source and a receiver are moving relative to one another, the frequency of the received signal will not be the same as the source. When they are moving toward each other, the frequency of the received signal is higher than the source. And when they are approaching each other the frequency decreases. This is called the Doppler Effect. An example of this is the change of pitch in a car's horn as it approaches then passes by. This effect becomes important when developing mobile radio systems. The amount the frequency changes due to the Doppler Effect depends on the relative motion between the source and receiver and on the speed of propagation of the wave.

Implementation of OFDM

An OFDM system was modeled using Matlab (version 6.5) to allow various parameters of the system to be varied and tested. The aim of this simulation was to measure the performance of OFDM under different channel conditions and to allow for different OFDM configurations to be tested. Four main criteria were used to assess the performance of the OFDM system. They are tolerance to multipath delay spread, peak power clipping, channel noise and time synchronization errors, (Tsai and Zhang, 2016). The OFDM system was modeled using Matlab as shown in Figure1. A brief description of the model is provided below.

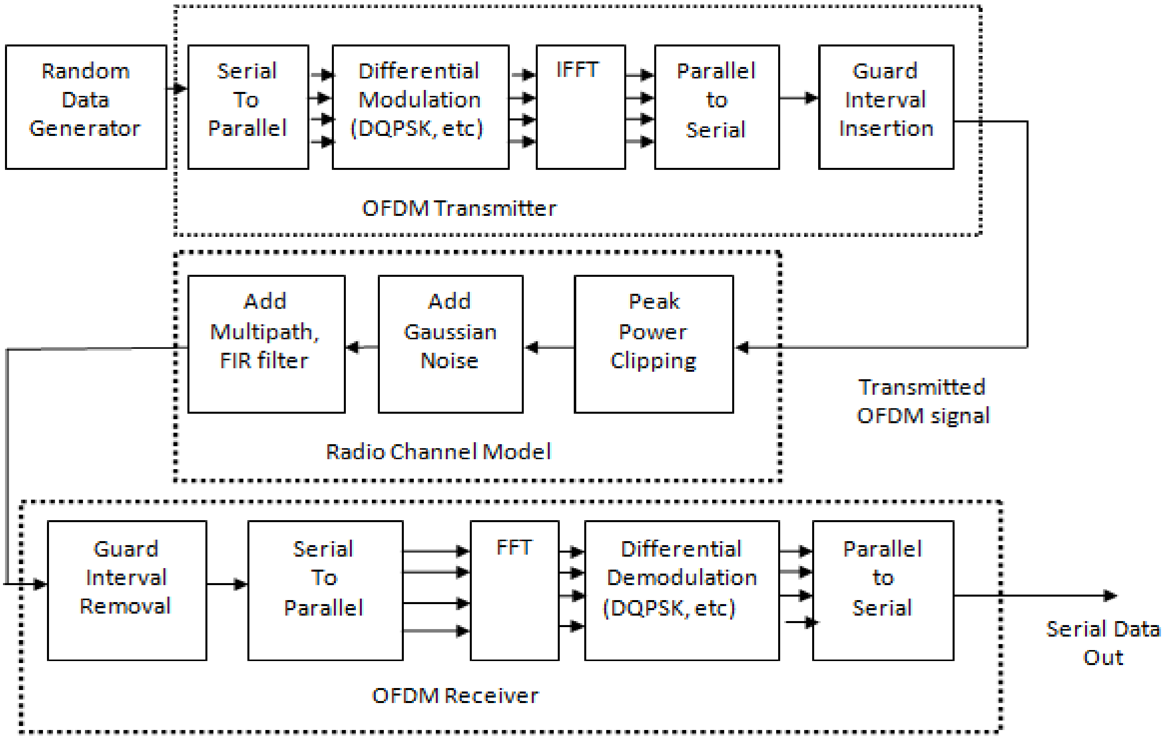

Figure1: OFDM Model used for Simulations

Serial to Parallel Conversion:

The input serial data stream is formatted into the word size required for transmission, for instance, 2 bits/word for Quadrature Phase Shift Keying (QPSK) and shifted into a parallel format. The data is then transmitted in parallel by assigning each data word to one carrier in the transmission.

Modulation of Data:

The data to be transmitted on each carrier is then differential encoded with previous symbols, and 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. The use of PSK produces a constant amplitude signal and was chosen for its simplicity and to reduce problems with amplitude fluctuations due to fading, (Thompson *et al.*, 2017)

Inverse Fourier Transform:
After the required spectrum is worked out, an inverse Fourier transform is used to find the corresponding time waveform. The guard period is then added to the start of each symbol.

Guard Period: The guard period used is made up of two sections. Half of the guard period time is a zero-amplitude transmission. The other half of the guard period is a cyclic extension of the symbol to be transmitted. This is to allow for symbol timing to be easily recovered by envelope detection. However, it was found that it is not required in any of the simulations as the timing could be accurately determine the position of the samples. After the guard has been added, the symbols are then converted back to a serial time waveform. This is then the base band signal for the OFDM transmission.

Channel: A channel model is then applied to the transmitted signal. The model allows for the signal to noise ratio, multipath, and peak power clipping to be controlled. The signal to noise ratio is set by adding a known amount of white noise to the transmitted signal. Multipath delay spread then added by simulating the delay spread using a Finite impulse response (FIR) filter (Van and Prasad, 2019). The length of the FIR filter represents the maximum delay spread, while the coefficient amplitude represents the reflected signal magnitude.

Receiver: The receiver basically does the reverse operation to the transmitter. The guard period is removed. The fast Fourier transform (FFT) of each symbol is then taken to find the original transmitted spectrum.

The phase angle of each transmission carrier is then evaluated and converted back to the data word by demodulating the received phase. The data words are then combined back to the same word size as the original data.

OFDM simulation parameters: Table 1 shows the configuration used for most of the simulations performed on the OFDM signal. An 800-carrier system was used, as it would allow for up to 100 users if each were allocated to 8 carriers. The aim was that each user has multiple carriers so that if several carriers are lost due to frequency selective fading that the remaining carriers till allow the lost data to be recovered using forward error correction. For this reason, any carrier less than 8 carriers per user would make this method unusable. Thus 400 carriers or less was considered too small. However more carriers were not used due to the sensitivity of OFDM to frequency stability errors, Thompson, *et al.*, 2019). The greater the number of carriers a system uses, the greater it required frequency stability. For most of the simulations the signals generated were not scaled to any particular sample rate, thus can be considered to be frequency normalized. Three carrier modulation methods were tested to compare their performances. This was to show a tradeoff between system capacity and system robustness. Differential Binary Phase Shift Keying (DBPSK) gives 1 b/Hz spectral efficiency and is the most durable method, however system capacity can be increased using Differential Quadrature Phase Shift Keying DQPSK (2 b/Hz) and D16PSK (4 b/Hz) but at the cost of higher BER, (Pacheco and Hatzinakos, 2016). The modulation method used is shown as BPSK, QPSK, and 16PSK on all of the simulation plots, because the differential encoding was considered to be an integral part of any OFDM transmission.

Table1: OFDM system parameters used for simulations

Parameter	Values
Carrier Modulation used	BPSK, QPSK,16PSK
FFT size	2048
Number of carriers used	800
Guard Time	512 samples (25%)
Guard Period Type	Half zero signal, half a cyclic extension of the symbol

Simulation with 4-QAM
The OFDM system was simulated with the following parameters

Tu=224e-6; %useful OFDM symbol period; T=Tu/2048; %baseband elementary period; G=0; %choice of 1/4, 1/8, 1/15 and 1/32;Delta=G*Tu; %guard band duration; ;Ts=Tu+delta; %total

OFDM symbol period; Kmax=1705; %number of subcarriers; Kmin=0; FS=4096; %IFFT/FFT length; q=10; %carrier period to elementary period ratio
fc=q*1/T; %carrier frequency; Rs=4*fc; %simulation period; t=0:1/Rs: Tu; tt= 0: T/2: Tu; Repeat = 68; % one OFDM frame (68 OFDM symbols) is sent, symbol by symbol; SNR_dB = 0:2:16

Simulation with 64 QAM

Here the OFDM system was simulated with the following parameters.
N = 64; % number of carriers - 48 data, 4 pilot, 12 unused; L = 8; % oversampling factors; Symbols = 100; % number of OFDM symbols to simulate; Rate=1/2/4/8---------BPSK/QPSK/16QAM/64QAM

Results

When we simulated for OFDM using 4 QAM and 64 QAM with 800 carriers and Guard sample of 25%, figures 2, 3, 4, 5, 6, 7 and 8 resulted. Figure 2 shows the transmitted 4 QAM constellations which range from -1 to 1. Figure 3 is the received 4 QAM constellation, while Figure 4 is the graph of the Symbol Error Rate versus SNR (in dB) of the 4 QAM simulated data.
Figure 5 shows the transmitted 64 QAM constellations which range from -30 to 30. Figure6 is the result of the OFDM time domain signal, while Figure7 shows the result of the Approximate OFDM spectrum. Also, Figure8 is the BPSK BER performance of OFDM in an AWGN channel. Comparison of OFDM in AWGN channels is summarized in table 1 below.

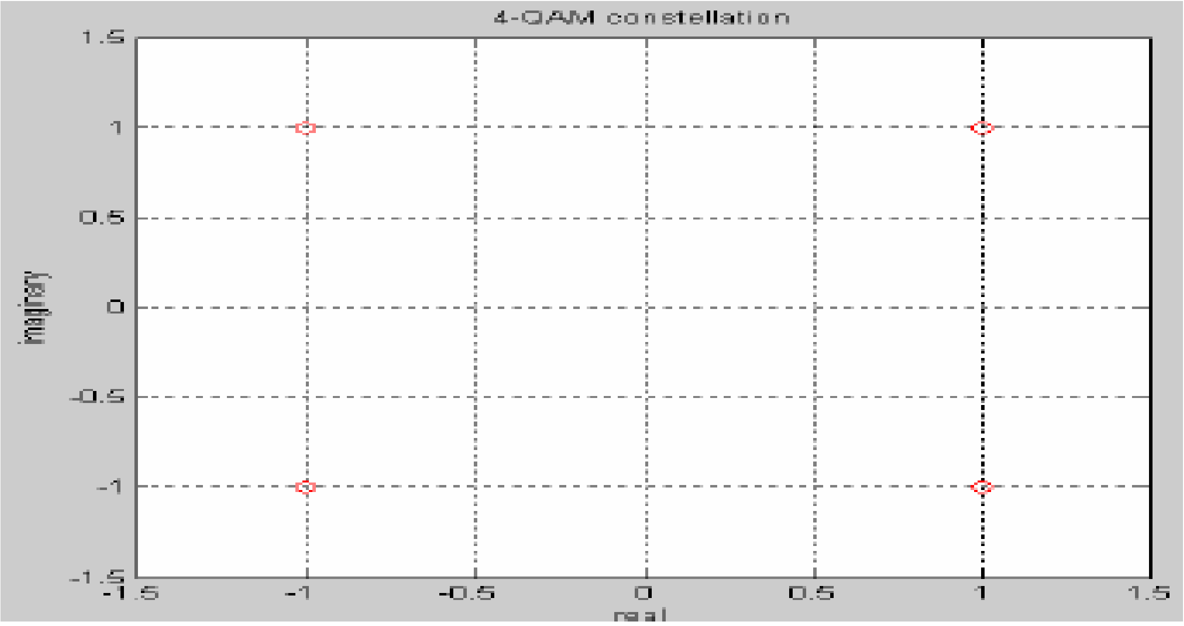

Figure 2: 4 QAM constellations

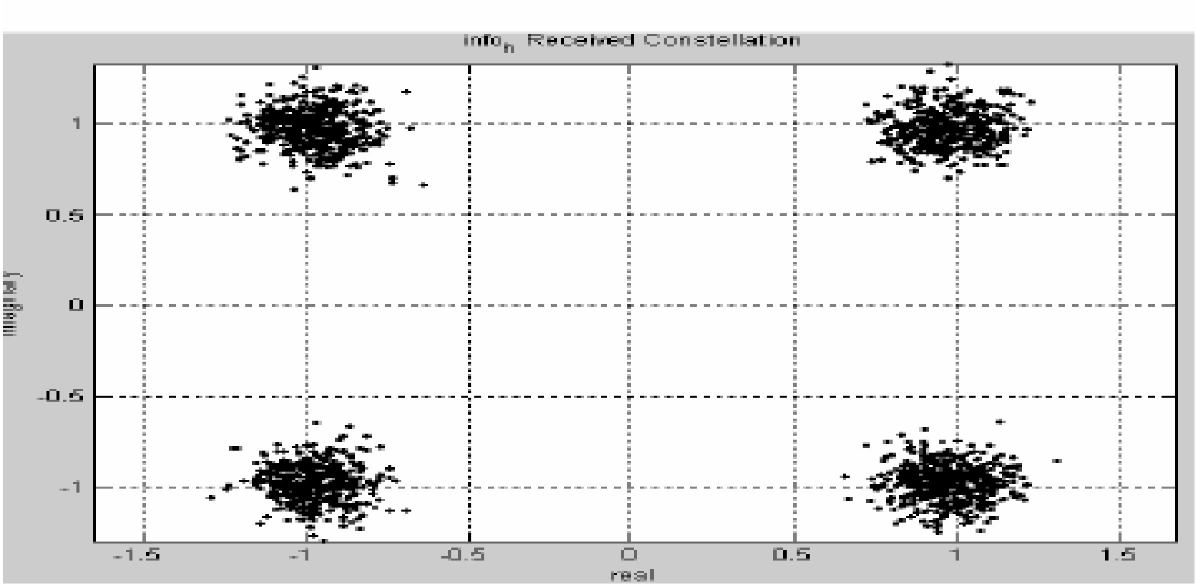

Figure3: Received 4 QAM constellation

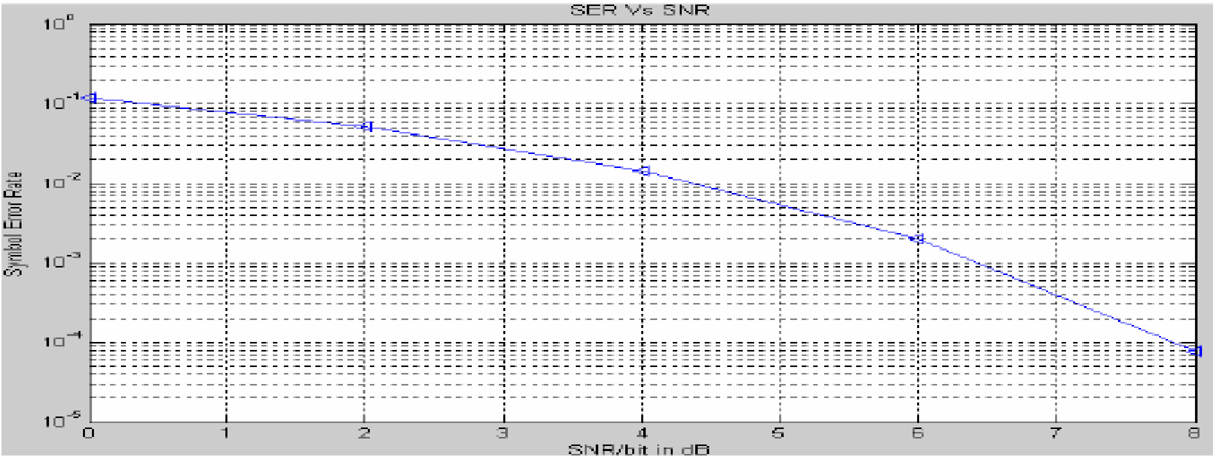

Figure 4: Symbol Error Rate versus SNR (in dB)

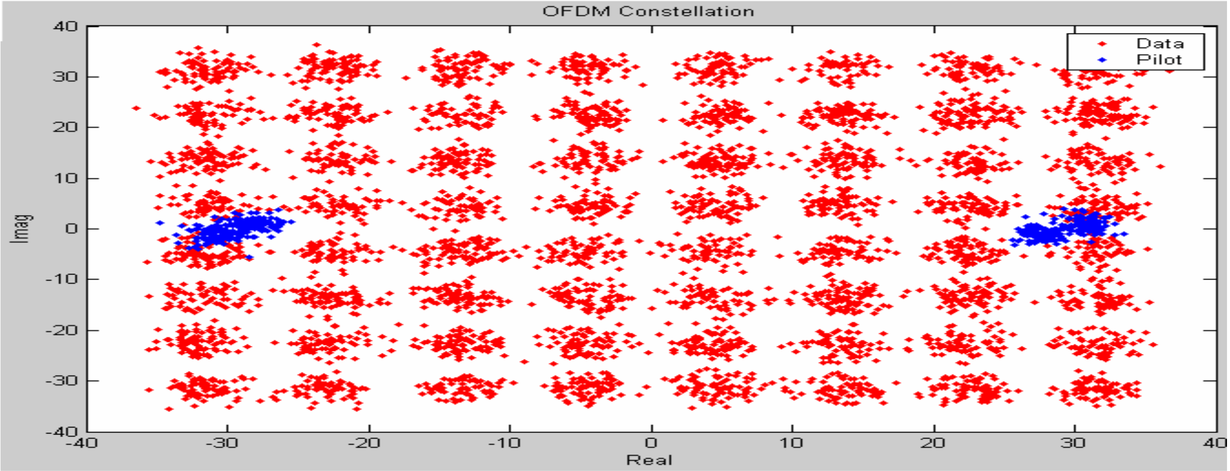

Figure 5: OFDM constellation

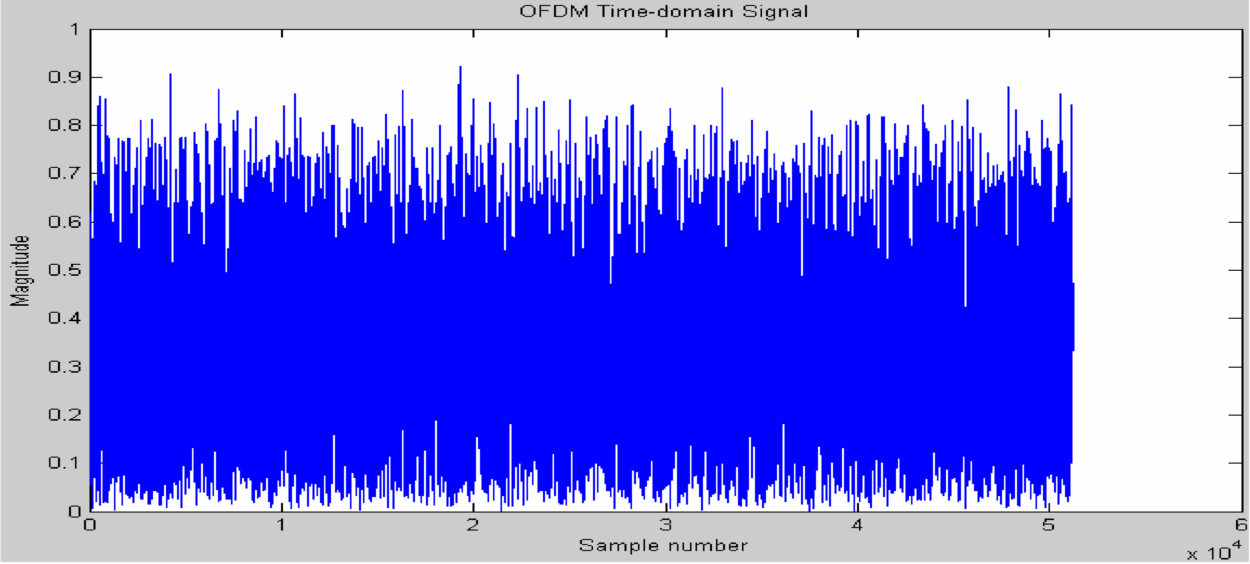

Figure 6: OFDM time domain signal

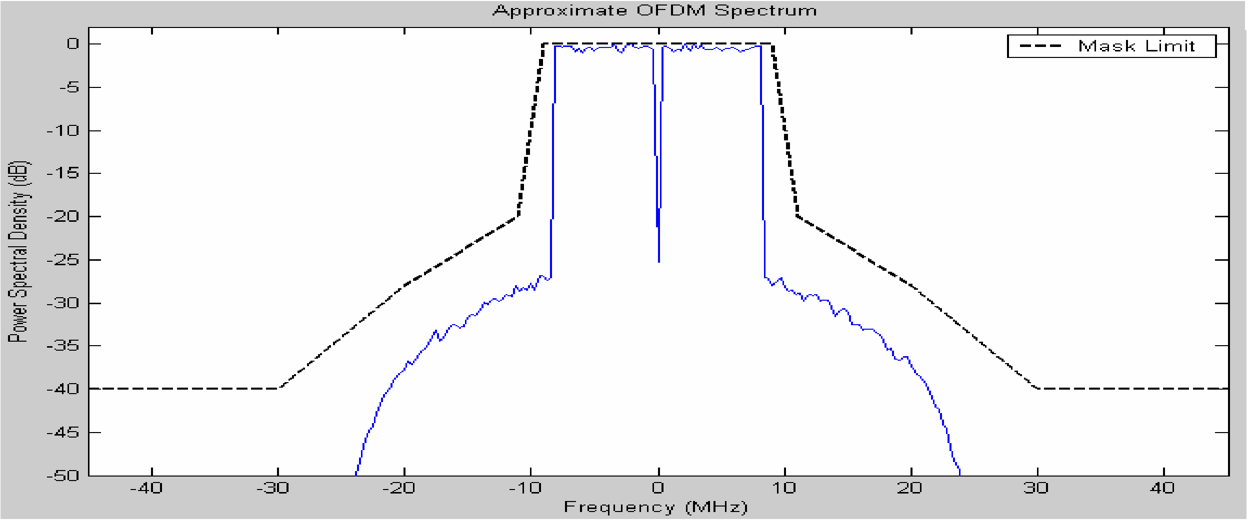

Figure 7: Approximate OFDM spectrum

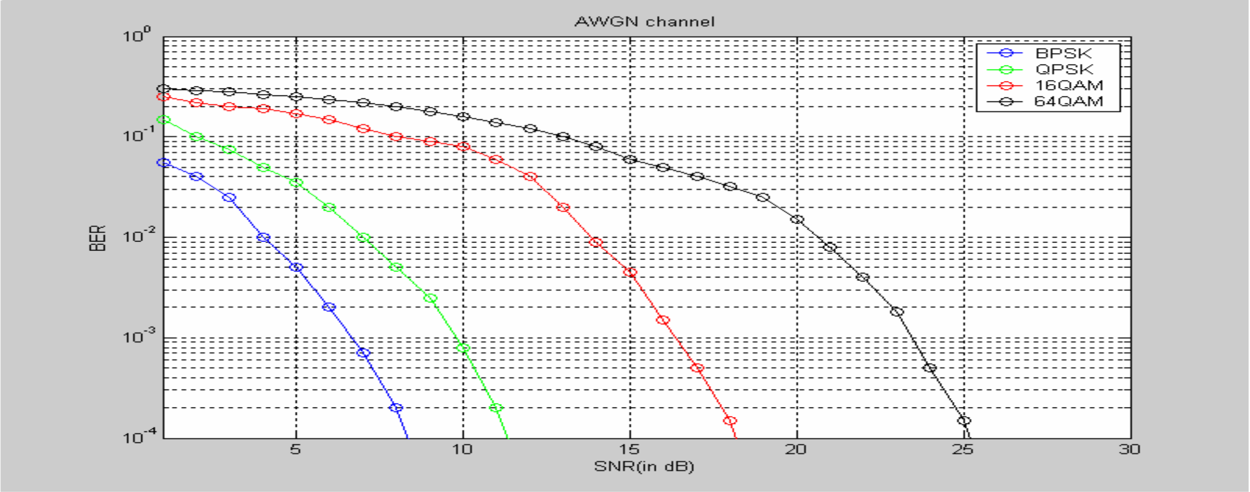

Figure8: BPSK BER performance of OFDM in an AWGN channel

Table 1: Comparison of OFDM in AWGN channels

OFDM Parameter	Spectral Efficiency	Capacity	BER
BPSK	High	Less	High
QPSK	Less	High	Less

Conclusion

In this paper, OFDM system was implemented in Matlab and the performance was evaluated for different simulation parameters. Here two carrier modulation methods were tested to compare their performances. This was to show a tradeoff between system capacity and system robustness. The following points can be drawn from the study presented in this paper. BPSK gives 1 b/Hz spectral efficiency and is the most durable method but system capacity is less. QPSK can be used to increase system capacity up to 2b/Hz but BER is more compared to BPSK. From table 1, since the BER is high in BPSK, then BPSK modulation method is the best to apply in an OFDM channels. The result also shows that additional symbols across time frequency increases the rate of transmission and bandwidth without changing the type of modulation employed.

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