Channel estimation for image restoration using OFDM with various digital modulation schemes

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Abstract. Channel or spectral estimation is a ground-breaking feature in wireless communication systems as it helps in obtaining information about a wireless channel at any state of time. Employing this can help in reducing the intensity of noise and bit error rate (BER). Here, images are processed, channels are estimated and image restoration is being done. Orthogonal Frequency Division Multiplexing (OFDM) is looked upon as a very popular multiplexing cum modulation technique used in wireless communication systems and so, it is selected to play a cardinal role in channel estimation. The LMS algorithm is preferred in this technique since it is a simpler technique and provides results which are desirable. To simulate realistic conditions, OFDM signal is passed through Additive White Gaussian Noise (AWGN) and also a multipath fading channel. In this paper, an FFT based OFDM, adopting several digital modulation techniques like BPSK, QPSK, 8PSK and 16QAM is being implemented on images. The values of BER is observed for different values of SNR and a comparison is drawn out for the aforementioned modulation techniques. Results prove that BPSK provides the least BER for a particular value of SNR and hence, it can be observed to give the best performance.

1. Introduction
Channel estimation functions help in estimating channel response in the spectrum which in turn aids in signal recovery. In this case, images are being recovered after being introduced to Additive White Gaussian Noise. Using OFDM as its multicarrier digital modulation scheme and single carrier modulation schemes for example, BPSK or QPSK, channel estimation is done to select the best modulation scheme which is compatible with OFDM, by observing their bit error rates and analysing the system performance accordingly. OFDM is a multiplexing scheme which can be incorporated in the present day for most wireless communications. It is used in modern communication fields such as, Cellular 4G, Wireless Networks, Digital Subscriber Line (DSL), Digital Television, Power Line Networks etc. Looking into Orthogonal Frequency Division Multiplexing, ‘orthogonal’ is a word which explains about two or more objects acting independently. Neighbouring orthogonal signals do not show any interference because they act independently. OFDM is a distinction of FDM and it is a much better version of it. While FDM operates on dividing the available bandwidth into different non-overlapping subchannels, in OFDM, subchannels are closely spaced (actually overlapped). Therefore, more data transmission is allowed by OFDM in comparison to FDM. Albeit the subcarriers are closely spaced, guard bands or guard intervals are also inserted between subchannels to avoid interference so that different signals can communicate freely. Thus, elimination of Inter Symbol Interference (ISI) is made possible by introducing guard intervals and addition of a cyclic prefix extension to the symbol in OFDM.
Thus, it can be observed that OFDM allows for better utilization of the available bandwidth, and offers faster transmission of data than FDM, simultaneously preventing interference between signals. High spectral efficiency can be seen in OFDM when compared to other spread spectrum methods. It is robust to ISI, narrowband co-channel interference. Also, implementation cost is lesser because this technique is done using FFT/IFFT.

Figure 1 depicts a MATLAB plot where the sensitivity of the subcarriers of the OFDM modulated signal can be seen[1].

![Figure 1. MATLAB plot of OFDM subcarriers.](image)

2. Baseband System Model

Displayed in Fig. 2 is a typical block diagram for baseband OFDM systems. In practice, generation of OFDM signal takes place with the help of Inverse Fast Fourier Transform (IFFT) algorithm on subcarriers and Fast Fourier Transform (FFT) algorithm on the acquired signal. A binary stream of data is shifted into the parallel blocks by the Serial to Parallel shifter. Constellation Mapper maps these parallel blocks to the symbols according to the selected modulation scheme (E.g.: - BPSK, QPSK, 16-QAM). Data is passed on to the time domain by using IFFT. Once in the time domain, the signal is shifted from parallel blocks to serial stream by Parallel to Serial Shifter. Cyclic Prefix Extension is added to combat ISI (Inter Symbol Interference). Multipath fading channel Now, the OFDM signal is subjected to fading channel (multipath) and AWGN is added to OFDM signal. Removal of cyclic prefix takes place at the receiver end. The data is shifted to parallel blocks so that it is processed by the Serial to Parallel Shifter. The FFT is used to shift data into frequency domain. Now, once in the frequency domain, channel estimation is applied. In this case, the LMS or least squares estimation is used. The data is demodulated using the same modulation scheme at the receiver end. The received symbols are converted into bits by the Constellation De-mapper. Finally, these bits are shifted from parallel blocks to a serial binary stream by the Parallel to Serial Shifter [2].
3. Channel Modelling
OFDM transmission takes place through a multipath fading channel with noise. The time domain OFDM signal, impulse response of the channel, AWGN and the corrupted OFDM signal are denoted by $x(n)$, $g(n)$, $w(n)$, $y(n)$, respectively. The following equation (1) represents $y(n)$,

$$y(n) = x(n) \ast g(n) + w(n)$$  \hspace{1cm} (1)

Since $w(n)$ is AWGN, it is dropped out of the equation for estimation purposes because it has zero mean. The equation for $y(n)$ is Equation (2),

$$y(n) = x(n) \ast g(n)$$  \hspace{1cm} (2)

Equation (2) in the frequency domain is described as shown in Equation (3),

$$Y(\omega) = X(\omega)G(\omega)$$  \hspace{1cm} (3)

By measuring the response $Y(\omega)$ to a known input signal $X(\omega)$, channel frequency response $G(\omega)$ is estimated as seen in Equation (4),

$$\hat{G}(\omega) = \frac{Y(\omega)}{X(\omega)}$$  \hspace{1cm} (4)

With an estimate of the channel, the original OFDM signal in frequency domain is estimated as,

$$\hat{X}(\omega) = \hat{G}(\omega)^{-1}Y(\omega)$$  \hspace{1cm} (5)

This process is referred to as Least Mean Squares channel estimation where $X(\omega)$ is known as the pilot signal. The following parameters are used in all the simulations as shown in Table 1.

| Table 1. Parameters used |
|--------------------------|
| FFT Size | Cyclic Prefix Length |
|-----------|----------------------|
| 64        | 16                   |

Figure 2. Typical OFDM Baseband System.
4. Results of Simulation
The OFDM system is simulated on MATLAB which undergoes multipath fading effects. The system implements an FFT with size 64 and a prefix extension length of 16 is used. The BER of various modulation schemes in an OFDM system are examined at different SNR values.

4.1. Binary Phase Shift Keying
BPSK consists of two points on the in-phase axis vs. the Quadrature axis. It matches one bit to one symbol.

The results of channel estimation using LMS algorithm and BPSK constellation mapping and demapping scheme can be observed in restored images at 5 dB, 10 dB, 15 dB and 20 dB SNR is shown in Figures 3a, 3b, 3c and 3d respectively.

- 5dB SNR
  - 0.07 BER

- 10dB SNR
  - 0.011 BER

- 15dB SNR
  - 0.0034 BER

- 20dB SNR
  - 0.0021 BER

The results of channel estimation using LMS algorithm and BPSK constellation mapping and demapping scheme can be observed in restored images at 5 dB, 10 dB, 15 dB and 20 dB SNR is shown in Figures 3a, 3b, 3c and 3d respectively.
4.2. Quadrature Phase Shift Keying

QPSK consists of four points on the in-phase axis vs. the Quadrature axis. It matches two bits to one symbol.

The results of channel estimation using LMS algorithm and QPSK constellation mapping and demapping scheme can be observed in restored images at 5 dB, 10 dB, 15 dB and 20 dB SNR is shown in Figures 4a, 4b, 4c and 4d respectively. Simulations were done for 8 PSK and 16 QAM as well. The results of BER for all modulation schemes are tabulated in Table 2 as given below.
Table 2. Bit-error rates for both modulation schemes at different SNRs.

|       | BPSK | QPSK | 8 PSK | 16 QAM |
|-------|------|------|-------|--------|
| 5dB   | 0.07 | 0.2  | 0.34  | 0.37   |
| 10dB  | 0.011| 0.13 | 0.28  | 0.31   |
| 15dB  | 0.0034| 0.076| 0.23  | 0.28   |
| 20dB  | 0.0021| 0.064| 0.2   | 0.27   |

It can be well observed that BPSK provides lesser bit error rates when compared to any other modulation scheme at the same SNR, which means probability of error is lower. The above simulation can be repeated for higher values of SNR and similar results can be observed. In this simulation, it has been observed that out of all the different modulation schemes, BPSK shows a better performance and portray efficacy when combined with OFDM. A robust performance to noise and ISI is shown by BPSK when compared to QPSK, 8PSK, 16-QAM.

Primary related work deals with different methods of channel estimation. However, this simulation is exclusively implemented with the usage of least squares method of channel estimation. Many other methods in time and frequency domain can also be implemented.

5. Simulation of BER vs. Eb/N0 curves for OFDM signals in AWGN channels

Multicarrier transmissions can be of different types and one of a special case is OFDM. A line of data stream goes over many lower rate subcarriers [3]. OFDM can be portrayed as a mix of multiplexing and modulation.

Eb/N0 is an established signal to noise interference ratio (SNR) measure in digital communication. It is also known as SNR per bit and when bit error rate or probability of error has to be measured for various digital communication systems, it is notably used [4].

Applying OFDM is observed to increase the performance of the system. From Figure 5 and Figure 6, it can be observed that as the SNR is increased, the Probability of error (BER) tends to decrease. AWGN is being used here as it simulates a generalized fading channel virtually on MATLAB.

A BER of $10^{-5}$ is achieved when SNR is 9 dB for BPSK-OFDM systems. However, the same BER can be observed only at 9.5dB.

A minute difference is seen in their SNR requirement, which can affect the system performance. Greater SNR requirement implies that greater energy is required to reduce the probability of error. Hence, BPSK can be viewed as an optimal modulation technique in terms of energy as well. This simulation was to just prove that as SNR is increased gradually, the probability of error can be reduced drastically and there is a possibility of it being a perfect transmission with BER = 0.
6. Conclusions and Future Scope

As demonstrated in the above approach, when the distorted image in the form of a signal appears at the FFT-OFDM receiver, it encounters effects of multipath fading channel and AWGN. LMS algorithm is applied to recover the original image from the distorted signal or to estimate the channel and the output image is predicted with much clarity by increasing the signal to noise interference ratio [5]. It can be understood that BPSK gives least value of BER = 0.0021 at 20dB SNR when compared to other modulation schemes with OFDM. Thus, the need for reduced probability of error can be satisfied by increasing the value of SNR. It can be applicable to wireless communication technologies in today’s world as well.

This project was initiated due to the unprecedented need for less distortion and inaccuracies in wireless communication of signals. Future scope for this experiment can involve the use of transmission and reception of audio/video signals through OFDM and different binary modulation schemes can be applied as represented in the above sections. The LMS algorithm can also be replaced with a faster but complex algorithm known as MMSE [6].

References

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