International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 11 (2015) pp. 29527-29537

http://www.ripublication.com

Channel Estimation of OFDM System Based on PACE Using LAB VIEW

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Abstract

This paper presents an approach to combat ISI in Orthogonal Frequency Division Multiplexing (OFDM) and thereby channel estimation technique. OFDM technique offers high data rate. Channel Estimation techniques have been successfully applied to the basic OFDM systems to obtain a remark ableenhancement. Channel estimation is a difficult task in fading environment. This paper analyzes the degradation effect of comb type subcarriers in OFDM systems in the Gaussian channel based on the estimation performance. The effects of Inter Symbol Interference (ISI) and Inter Channel Interference (ICI) are reduced by the splitting process. This splitting process also decreases the rate of stream of data connected with distinct subcarriers. In this paper OFDM is implemented using Lab view based on channel estimation techniques. The work starts with basic architecture of OFDM and their implementation using QAM followed by channel estimation techniques of OFDM using MATLAB and finally concluded the importance of estimation based on the performance achieved using Lab view. It is concluded that the BER analysis shows approximately same results when compared in the simulators.

Index Terms: OFDM, Multipath fading, ICI, ISI, LS, and MMSE, Lab view

Introduction

Many mobile and wireless applicationschannelsrequire high data rate transmission. When duration of symbol is decreased, then the data rate is increased. In other words, if the number of data increases, data rate is decreased. Inter symbol interference (ISI) is caused by dispersive fading of wireless mediums. To limit ISI, the delay spread of wireless channel must be very less than the symbol duration. The total available channel is divided into number of sub channels and transmitting it in parallel manner results in high speed transmission. Also duration of symbol can be increased to reduce ISI.Orthogonal Frequency Division Multiplexing (OFDM) is most commonly employed in wireless communication systems because of the high data rate transmission.Also it has high bandwidth efficiency and ability to overcome multi-path delay. It has been used in broadband multimedia wireless services [1].

The opportunities provided by flexibility of OFDM are to use advanced techniques such as, adaptive loading, transmitter and receiver diversity and to improve efficiency of transmission.For asymmetric (DSL) digital subscriber line, Cioffi and his group have investigated OFDM with performance optimization, which is called as Discrete Multiple Tone (DMT). They made their earlier inventions on practical loading algorithms for DMT or OFDM systems

Minimum Mean Square Error (MMSE) and Least Square

(LS) arethe two common available channel estimation techniques to estimate the channel response when we use training symbols. The use of training sequence provides the required performance, but degrades due to the addition of pilot information. There is a compromise between the required performance and the efficiency of the system.If we can negotiate on the performance, then the efficiency increases.But in some cases we cannot ignore this fact sowe must use some estimation techniques to achieve required performance at the cost of less efficiency [2].

In this paper, we surveyed about OFDMfor wireless communications. In Section II, We start with basic OFDMsystem architecture and cyclic prefix technique for improving the performance of the system. In Section III, We describe about various OFDM-relatedmodulations and channel estimation techniques. In Section IV, the simulation Environment and their results are described and section V describes conclusion of the paper.

System Architecture

In this section, we describe the basic system architecture of OFDM and introduce techniques to improve the performance of wireless communications by using OFDM.

Orthogonal Frequency Division Multiplexing

The word “orthogonal” in Orthogonal Frequency Division Multiplexing indicates that there is a clear mathematical relationship between the frequencies of the carriers in the system. In a normal Frequency Division Multiplexing system, the conventional filters and demodulators are used for receiving the many carriers which are spaced apart in such way. In that receivers, guard bands have to be introduced between the distinct carriers and the spectrum efficiency of the reduces in frequency domain by the introduction of these guard bands [6]. It is possible, however, for arranging the carriers in an OFDM signal so that the sidebands of the individual carriers overlap and still, the signals can be received without any adjacent carrier and symbol interference.

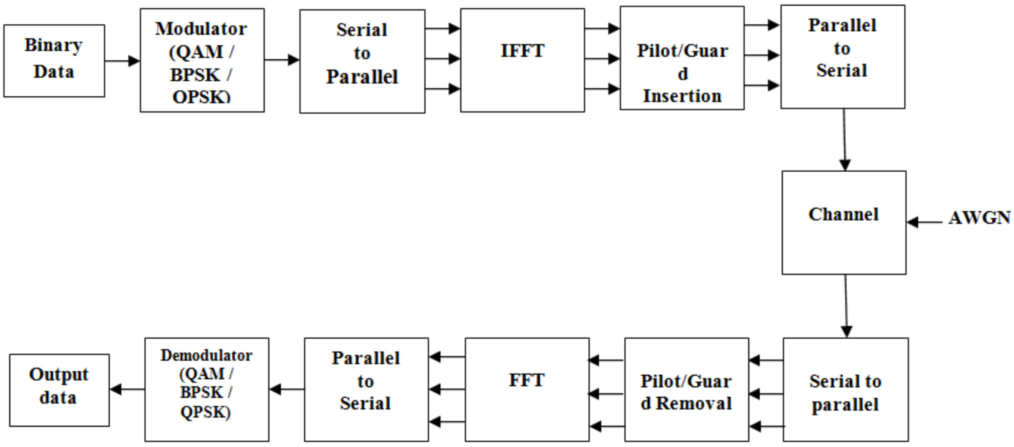

Figure 1: OFDM System

In order to do this the carrier signals must be mathematically orthogonal. The receiver acts like a demodulator bank, translating each carrier signals down to DC electrical signal, the resulting signal then being integrated over a symbol period to recover the binary or original data transmitted.

The integration process results in a zero contribution, if the other carriers all beat down to frequencies which is in time domain, have a whole number of cycles with the symbol period (t). Thus these carriers are orthogonal, when the carrier spacing is a multiple of 1/t.

Let $\{b_{n,i}\}_{i=0 \text{ to } N-1}$ with $E|b_{n,i}|^2=\sigma_b^2$ be the complex symbols to be transmitted at the n^{th} OFDM block, then the modulated version of OFDM signal can be represented by

$$b_n(t) = \sum_{i=0}^{N-1} b_{n,i} e^{j2\pi i\Delta f t}, 0 \le t \le T_b \quad (1)$$

where T_b, Δ_f and N are the symbol duration, the sub channel space and the number of sub channels of OFDM signals respectively. For the receiver for demodulating the OFDM signal, the symbol duration must be long enough such that the product of symbol duration and the sub channel space is unity (i.e.) $T_b\Delta_f=1$, this is also called the orthogonal condition since it makes $e^{-j2\pi i\Delta ft}$ orthogonal to each other for different 'i' values. By thiscondition, the receiver can detect the transmitted symbols($b_{n,i}$) by

$$b_{n,i} = \frac{1}{T_b}\int_0^T b_n(t) e^{-j2\pi i\Delta ft} dt \quad (2)$$

if there is no channel distortion.

The sampled version of the baseband OFDM signal *b(t)* in (1) can be expressed as

$$b_n\left(m\frac{T_b}{N}\right) = \sum_{i=0}^{N-1} b_{n,i}\, e^{j2\pi i\Delta f m\frac{T_b}{N}}$$

The equation (3) is the Inverse Discrete Fourier Transform (IDFT) of the symbols $\{bn,i\}_{i=0}^{N-1}$ which is to be transmitted and they can becalculated efficiently by Fast

Fourier Transform (FFT). It shows that the demodulation of the modulated message signal at the receiver is easily performed than DFT instead of the integral in equation (2).

A cyclic prefix (CP) is also called as guard interval which is critical for OFDM toavoid the Inter Block Interference (IBI) or Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI), made by the delay spread of the wireless channels.

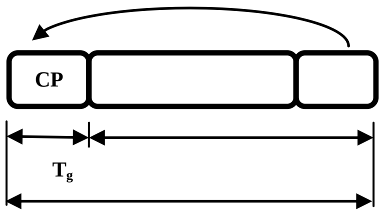

Figure 2: Cyclic Prefix

The CPis usually inserted between adjacent blocks in OFDM. The function of the Cyclic Prefix is shown in Figure2. Without this CP, the length of the symbol in OFDMblock is T_b, as shown in (2). With this CP, the length of the symbol in OFDM block is extended to $T=T_g+T_b$ and can be written as

$$\widetilde{b_n}(t) = \sum_{i=0}^{N-1} b_{n,i} e^{j2\pi i\Delta f t}, -T_g \leq t \leq T_b \quad (4)$$

Here,$\widetilde{b_n}(t) = b_n(t + T_b)at-T_g \leq t \leq 0$ so, it is called as CyclicPrefix(CP).

The impulse response of a wireless channel can be expressed by

$$h(t) = \sum_k \gamma_k \delta(t - T_k) \quad (5)$$

where T_k andγ_k are the delay and the square of the complex amplitude i.e. $(amplitude^2)$of the k^{th} path, respectively and the received signal can be written as

$$x_n(t) = \sum_k \gamma_k \bar{s_n}(t - \tau_k) + n_{\boldsymbol{awgn}}(t) \quad (6)$$

where$n_{\boldsymbol{awgn}}(t)$indicates the Additive White Gaussian Noise (AWGN) at the receiver. As shown in the Fig(2), $x_n(t)$ contains only the signal component n^{th} block in OFDM, when the value of t lies between τ_l and τ_u i.e. $\tau_l \leq t \leq \tau_u$. Where $\tau_l = -T_g + \tau_M$,$\tau_u = T_b + \tau_m$, $\tau_m = min_k\{\tau_k\}$ and $\tau_M = max_k\{\tau_k\}$; elsewhere, the signal received contains the signals from distinct blocks of OFDM.

If $0 \geq \tau_l$ and $\tau_u \geq T_b$, then $x_{n,i}$ can be written as,

$$x_{n,i} = \frac{1}{T_b}\int_0^{T_b} x_n(t) e^{-j2\pi f_i t} dt \quad (7)$$

$$x_{n,i} = \frac{1}{T_b}\int_0^{T_b} \left\{\sum_k \gamma_k \bar{s_n}(t - \tau_k) + n_{\boldsymbol{awgn}}(t)\right\} e^{-j2\pi f_i t} dt \quad (8)$$

$$x_{n,i} = H_i s_{n,i} + n_{\boldsymbol{awgn}(i)}, 0 \leq i \leq N-1\ ; n = 0,1,2,3 \ldots. \quad (9)$$

Where H_i indicates the wireless channel’s frequency response at i^{th} subchannel and which is defined as

$$H_i = \sum_k \gamma_k e^{-j2\pi i \Delta f \tau_k} \quad (10)$$

When Doppler spread exists, γ_k changes with time and will be a narrowband stochastic process.

The value $n_{\boldsymbol{awgn}(i)}$is known as the impact of AWGN at the receiver and is defined as

$$n_{\boldsymbol{awgn}(i)} = \frac{1}{T_b}\int_0^{T_b} n_{\boldsymbol{awgn}}(t) e^{-j2\pi f_i t} dt \quad (11)$$

It proved that $n_{\boldsymbol{awgn}(i)}$is independent identically distributed complex circular Gaussian. Its mean value is zero and varianceσ_n^2. Symbols transmitted are estimated with the help of H_i. For a single carrier system, the received signal is the convolution of the transmitted symbols and the impulse response of the channel with AWGN i.e. $\{b_n(t) * n_{\boldsymbol{awgn}}(t)\}$.

OFDM is very popular nowadays. Because of the impact of the channel are the multiples of the distortion at each sub channel. It makes signal detection in OFDM system and so OFDM is very simple.

The CP and Guard Intervals in OFDM is effectively avoids IBI. And more about them is discussed below.

1. The guard interval is used instead of the Cyclic Prefix i.e., no signal is transmitted instead of the CP, IBI and ICI can also be avoided.
2. By equation [4], the wireless channel's delay spread will cause both IBI and ICI, when its length is not long enough or there is no Cyclic Prefix or guard interval.

Inter-symbol Interference and Inter-carrier Interference caused by data symbols on adjacent subcarriers is referred to inter-carrier interference (ICI). Moreover, to reduce the ISI, a guard time is inserted at the beginning of each OFDM symbols before transmission and removed at the receiver before the FFT operation. If the guard time is chosen such that its duration is longer than the delay spread, the ISI can be completely eliminated [6].

Channel Estimation

Usually, with the use of pilot symbols, the Channel estimation in OFDM is performed.In flat fading, each sub carrier is used and for FDM, single-carrier flat fading system techniques are directly applicable. In those systems, Pilot Symbol Assisted Modulation (PSAM) on flat fading channels, insertion of known pilot symbolsare involved in a stream of data symbols [3].The channel estimation can be performed by either inserting pilot tones into all of the subcarriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol [4].There are basically two types of classification of Channel estimation in OFDM

1. **Pilot Based Channel Estimation:** Transmitting a known Symbols or data called Pilots
2. **Blind Channel Estimation:**It uses some underlying mathematical properties of data sent. So, no pilots required.

A. Features of Channel Estimation

- In the uplink, in order to enable the access point to estimate the uplink channel from the terminal to the access point, each terminal needs to send a pilot transmission separately.
- In the downlink, to estimate the response of the distinct downlink channels from access point to each of the terminals, a single pilot transmissionfrom an access point must be used by number of terminals.
- For an OFDM system, different effectivechannels are experienced by N sub bands, due to different effects offading and multipath. And also various complex channel gains are bonded with it.
- To perform the channel estimation, a pilot from the transmitter is sent and measured at the receiver.
- To obtain an accurate estimate of the channel response,adequate amount of pilot should be transmitted to the receiver.

B. Channel Estimation Algorithms

(i) Least Square(LS) Channel Estimation:

Transmitted symbols are used in LS channel estimation technique. Here, the design of the channel filter is made such that it is compatible with the transmitted symbols. Some advantages of LS algorithm are less complexity, implementation of this algorithm is easyand probability function is not requiredfor determining the channel response [2].

Let ‘k’ be the channel vector response, then LS estimation of the channel can be approximatedas

$$\widehat{g_{Ls}} = E\ L_{Ls} E^K X^K y$$

WhereL_{Ls}can be written as

$$L_{Ls} = (E\ X\ E^K X^K)^{-1}$$

The LS channelvectorestimation ‘k’ is given by

$$\widehat{g_{Ls}} = X^{-1} y$$

By considering the high energy taps, the LS channel estimation can be improved and this can bewritten as

$$\widehat{g_{Ls}} = T\ L'_{Ls} T^K X^K y$$

Where L'_{Ls} is written as

$$L'_{Ls} = (T\ X\ T^K X^K)^{-1}$$

(ii) Minimum Mean Square Channel Estimation (MMSE)

Comparing with LS, MMSE performs better,since ituses theinformation of Signal to Noise Ratio (SNR) and channel characteristics, to estimate the channel.Compared to LS, MMSE complexity is more. But by assumingthe flat response of Power Delay

Profile (PDP) and finite length sequence, Complexity in MMSE can be reduced and improves the performance [2].

Let 'k' be the channel vector response, then MMSE estimation of the channel can be approximatedas

$$\widehat{g_{MMSE}} = r_{kx}{r_{xx}}^{-1}x$$

where$r_{hx}$is a cross co-variance matrix which can be writtenas

$$r_{kx} = r_{kk}F^kY^k$$

And $r_{xx}$is an auto co-variance matrix and written as

$$r\_xx = YFr\_kk\ F^\wedge k\ Y^\wedge k + \sigma^\wedge 2\ I\_n$$

The response of Channel estimation in frequency domainis given by

$$\widehat{g_{Ls}} = F\hat{h} = FLY^KF^Kx$$

Where 'F'denotes the DFT-matrix that is orthonormal and 'L' can be written as

$$L = r_{xx}[(FY\ F^KY^K)^{-1}\sigma^2 + r_{xx}]^{-1}(FY\ F^KY^K)^{-1}$$

By comparing the channel estimation techniques explained, LS channel estimation is better than MMSE technique. Because the bit error rate (BER) is lower than MMSE [5]. Here, we used the comb-type pilot channel for satisfying the need of equalization when the channel changes from one OFDM block to another one subsequent OFDM block[4]. Since it tracks fast fading channels and performs better. The LS estimate issusceptible to Inter Carrier Interference (ICI) noise. To compromise complexity, the MMSE channel estimation is proposed[4].At each iterations, MMSE includes the matrix inversion which is a simplified version and is calculated only once. The low-rank approximation by using singular value recombination is used to reduce the complexity. The figure (3) shows the comb type pilot arrangement.

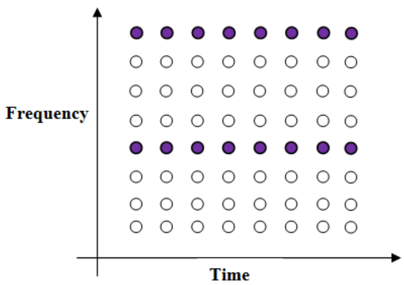

Figure 3: Comb Type Pilot Arrangement

C. Proposed Method

In this paper, comb type channel estimation is done using labview. The labview model has the following blocks for OFDM channel estimation which is shown in Figure 4 based on [7].

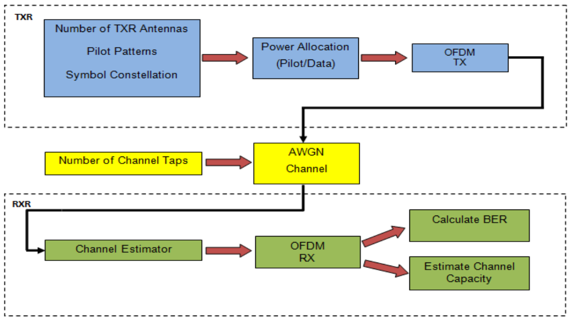

Figure 4: Block diagram of OFDM Simulator

- **Pilot Sequence Generator:** Three types of pilot patterns generator for OFDM systems is implemented. To guarantee the orthogonality between channels, pilot symbols should be orthogonal in either time, frequency, or code. This generator is fixed for 4 pilot symbols per an OFDM symbol, however, it can be changed to other numbers by simple modification.
- **Random Bit Generator and symbol mapper/demapper:** Simple VI's which generate random bit according to the input value and mapping bits to BPSK/QPSK symbols and vice versa.
- **Pilot-to-data Power Ratio (PDPR) VIs:** VI's which generate optimal PDPR value and pilot/data tone power according to the PDPR for various MIMO-OFDM system configurations are developed.
- **Subcarrier Allocator:** The VI is used to allocate pilot and data symbols for three different pilot patterns with given pilot power and data power.
- **OFDM Transmitter:** The VI generates OFDM symbols in either time or frequency domain according to a given pilot pattern and PDPR.
- **Channel and Noise:** The VI is used to generate multipath Rayleigh fading channel and AWGN noise according to input values such as the number of channel taps and SNR.
- **OFDM Receiver:** The MMSE receiver VI for OFDM systems. It also includes the part which can calculate the channel capacity lower bound with channel estimation error. Thus, this VI shows the BER performance and the channel capacity lower bound.
- **MMSE Channel Estimator:** The VI is used to estimate OFDM channel in a MMSE way according to three different types of pilot patterns namely independent, scattered, and orthogonal pilot patterns.

Simulated Results

In this paper, the simulation is previously carried using MATLAB with signal processing toolbox and concludes with LABVIEW simulation.

This paper simulates the OFDM signal transmission for the parameters listed as per the specified data in the table 1. The paper carries OFDM transmission for 64 subcarrier with 5 symbols. The modulation carried for OFDM transmission is QAM with N=4 and hence 16 QAM. Though we studied about different pilot arrangement, here comb type arrangement is followed. And we compare those results from MATLAB and LABVIEW. The work starts with analyzing suitable modulation scheme for modulation, out of which QAM is chosen.The following figure shows the ***BER*** vs. E_b/N_0 for QAM modulation scheme with different 'N' values. It shows the BER at 10^{-2} there is approximately 4 dB improvement as the value of N increases. Hence it shows BER is better for low value of 'N'.

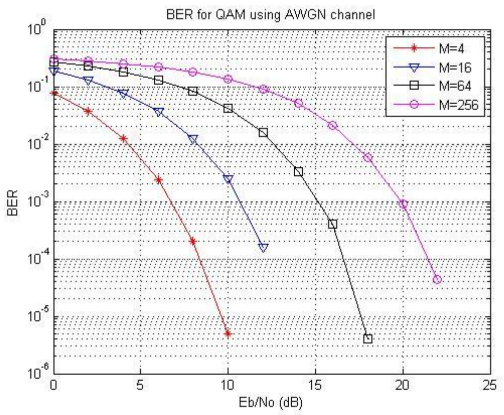

Figure 5: BER vs. $\mathbf{E_b/N_0}$of QAM

The following Figure 6 shows the simulation curve for BER of QAM using OFDM with simulated result and theoretical result. It is observed that there is only difference of approximately 2-3 dB between simulated and theoretical simulation.

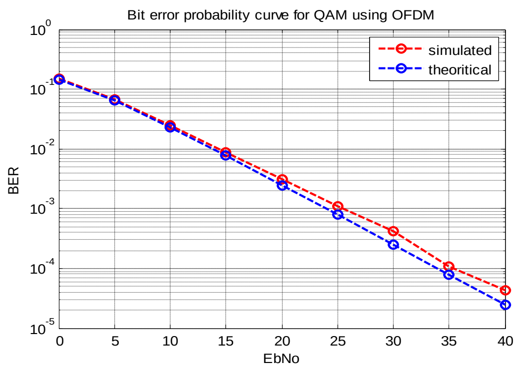

Figure 6: BER of QAM

The figure below shows the simulated results for OFDM for M=4 and M1, M2, M3=64.

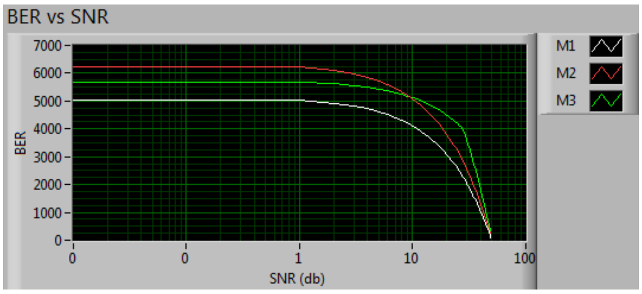

Figure 7: BER of OFDM for M=4

The figure below shows the simulated results for OFDM for M=8 and M1, M2, M3=256

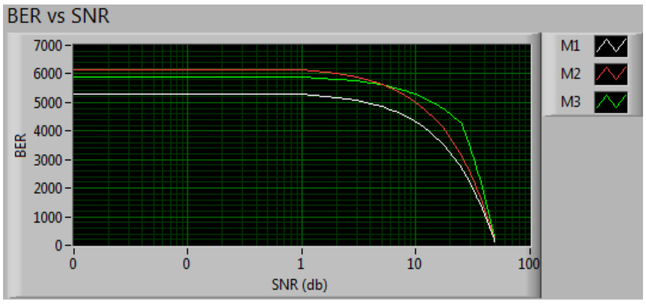

Figure 8: BER of OFDM for M=8

It is obvious from the above simulated results obtained for different values of N, that the roll-off rate is similar in both the cases, whereas the BER at 0dB SNR has slight difference.

Conclusion

Channel Estimation techniques have been successfully applied to the basic OFDM systems to obtain a remarkable enhancement. This paper analyzes the degradation effect of subcarriers in OFDM systems on the time-domain based on the estimation performance. Here we have studied and implemented OFDM in MATLAB using channel estimation techniqueswhich shows the BER vs. E_b/N_0 for QAM modulation scheme with different 'N' values. It shows the BER at 10^{-2} there is approximately 4 dB improvement as the value of N increases. Hence it shows BER is better for low value of 'N'. Further the above work is compared using lab view simulator for different values of M. The simulation results shows for lower values of M, the BER is better.

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