ANALYSIS AND IMPLEMENTATION OF OFDM SYSTEM AND CHANNEL ESTIMATION BASED IEEE 802.11A

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ABSTRACT

Channel estimation plays a very important role in any wireless communication system. Currently many related algorithms are a research hotpot. Basically channel estimation are classified into two types namely, pilot-based channel estimation and blind channel estimation. Pilot-based channel estimation estimates the channel information by obtaining the impulse response from all sub-carriers of pilot. The blind channel estimation uses statistical information of the received signals whereas pilot-based channel estimation is a practical and an effective method. This paper presents a pilot-based channel estimation of OFDM system and analyzes the degradation effect of pilot subcarriers in OFDM systems on the time-domain based on the estimation performance. The effects of Inter Symbol Interference (ISI) are reduced by the splitting process. This splitting process also decreases the rate of stream of data connected with distinct subcarriers. The paper starts with basic realization principle of OFDM system and analyzes OFDM in the frequency domain using spectral analysis method. The simulation results are shown using Matlab which compares the bit error rate (BER) performance of different modulation schemes and types of pilot and finally concluded the importance of estimation based on the achieved results based on IEEE802.11a.

Keyword: OFDM, channel estimation, ISI, LS, MMSE.

1. INTRODUCTION

The present scenario of wireless communication system field like DVB, Wimax, GPRS and other multimedia are in need of high data rate for transmission. Orthogonal Frequency Division Multiplexing (OFDM) is predominantly chosen because of several reasons, which include its high robustness to multipath fading at high data rate transmission. Further it is easy for implementation. OFDM is a multicarrier modulation technique and has paid lot of attention in wireless communication. OFDM transmits high rate data stream, mitigates multipath interference at the receiver, avoids large number of complementary modulators, demodulators and filters at the transmitter and receiver. Thus it uses modern DSP techniques like FFT. OFDM seeks inverse FT or DFT at the transmitter and FT or DFT at the receiver. Channel estimation are classified into two types namely, pilot-based channel estimation and blind channel estimation. The blind channel estimation uses statistical information of the received signals whereas the Pilot-based channel estimation estimates the channel information by obtaining the impulse response from all sub-carriers of pilot. The pilot-based channel estimation is a practical and an effective method due to its various advantages. The channel estimation in OFDM can be performed by either inserting pilot tones into all of the subcarriers of OFDM symbols or inserting pilot tones into each OFDM symbol. The former is known as block type pilot channel estimation and is best suitable in slow fading channel. The latter is known as comb type pilot channel estimation and is best suitable in fast fading channel. The estimation of block type pilot arrangement can be obtained by using several algorithms like Least Square (LS) or Minimum Mean Square Estimation (MMSE) algorithm. MMSE estimate proves better than LS estimate with 10-15 dB gain in SNR for the MMSE.

In [15], linear MMSE is performed with low rank approximation by using frequency correlation of channel to eliminate the primary drawback of MMSE, which is complex. As mentioned earlier, the comb type channel estimation satisfies its performance even in fast fading environment and it has been found usage of Pilot-aided channel estimation is a good choice of the pilot pattern and matches the channel behavior both in time and frequency domains. Here block type pilot arrangements were explored. In block type pilot arrangement, pilot signal is assigned to a particular OFDM block, which is sent periodically in time domain and is suitable for slow-fading. Comparing the symbols received, the pilots subcarriers with the symbols that have been transmitted gives an estimate for the channel frequency response at the pilots. The advantage for comb type pilots arrangement in channel estimation is the ability to track the variation of the channel caused by doppler frequency, it is observed that the Doppler effect can be reduced, and so this will increase the system mobility. There are many approaches for pilot aided channel estimation and it is necessary to consider at least the following factors for channel estimation (a) performance algorithm (b) complexity relative to the current processing power.

In OFDM, channel estimation consists of two steps, in which the first step involves the periodic channel sampling by virtue of known pilot symbols. This involves performing channel estimate instantaneously in each time slot by averaging the channel estimates calculated from each pilot symbol. And the second step involves channel tracking or interpolation, in which the tracking of the time varying fading channel is realized through a filter to obtain the channel estimates from the data symbols. The paper presented here compares the performances of OFDM data transmission over the channel one with simple transmission and other with channel estimation by measuring bit error rate with 16QAM, as modulation schemes and AWGN fading channels as channel models. Future lies in analysis of OFDM based on the spectral analysis of the transmission and reception using window function.

The remainder of this paper is organized as follows. Section II describes the OFDM system architecture used in this work. Section III develops a general framework of the channel estimation based on time domain techniques. Here spectral estimation is considered. Section IV presents the numerical results to justify the study of channel estimation scheme in OFDM and Section V concludes the paper.

2. OFDM

In this section, the basic system architecture of OFDM is explained. 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. At the receiver end, guard bands have to be introduced between the distinct carriers, which reduce the spectrum efficiency in frequency domain [6]. In OFDM, it is possible receive the signals without any adjacent carrier and symbol interference by arranging the carriers of sideband overlap.

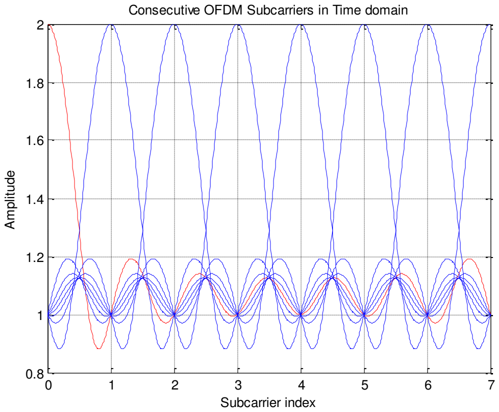

Figure-1. OFDM subcarriers.

In order to achieve this, the carrier signals must be mathematically orthogonal. The receiver acts like a demodulator bank, translating each carrier signals down to a 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 ina 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 being a multiple of 1/t.

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

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

where$T_b, \Delta_f$and N are the symbol duration, the sub channel space and the number of sub channels of OFDM signals respectively. At 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.) $T_b\Delta_f = 1$, which is also called the orthogonal condition since it makes $e^{-j2\pi i\Delta ft}$orthogonal to each other for different ‘i’ values. By this condition, the receiver can detect the transmitted symbols ($b_{n,i}$) by

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

If there is no channel distortion, the sampled version of the baseband OFDM signal *b(t)* in (1) can be expressed as

$$b_n\left(m\frac{T_b}{N}\right) = \sum_{i=0}^{N-1} b_{n,i}\, e^{j2\pi i\Delta f m\frac{T_b}{N}} \tag{3}$$

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 for avoiding the Inter Block Interference (IBI) or Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI), made by the delay spread of the wireless channels.

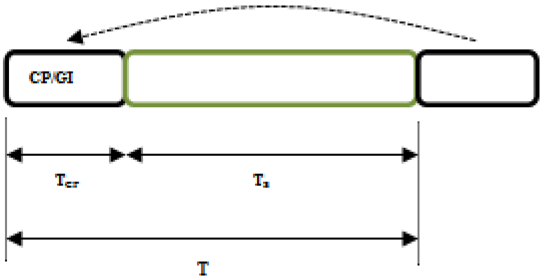

Figure-2. Cyclic prefix.

The CP is usually inserted between adjacent blocks in OFDM. The function of the Cyclic Prefix is shown in Figure-2. Without this CP, the length of the symbol in OFDM block isT_S, as shown in (2). With this CP, the length of the symbol in OFDM block is extended to $T = T_C + T_S$and can be written as

$$\widetilde{b_n}(t) = \sum_{i=0}^{N-1} b_{n,i} e^{j2\pi i\Delta f t}, \quad -T_C \le t \le T_S \qquad (4)$$

Here,$\widetilde{b_n}(t) = b_n(t + T_S)at-T_C \le t \le 0$ so, it is called as Cyclic Prefix (CP).

The impulse response of a wireless channel can be expressed by

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

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.

The received signal can be written as

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

where $n_{\boldsymbol{awgn}}(t)$ indicates the Additive White Gaussian Noise (AWGN) at the receiver. As shown in the Figure-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. $\tau_l \le t \le \tau_u$. Where $\tau_l = -T_C + \tau_M$,$\tau_u = T_S + \tau_m$, $\tau_m = min_k\{\tau_k\}$ and $\tau_M = max_k\{\tau_k\}$; elsewhere, the signal received contains the signals from distinct blocks of OFDM.

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

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

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

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

whereH_i indicates the wireless channel's frequency response at i^{th}subchannel and which is defined as

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

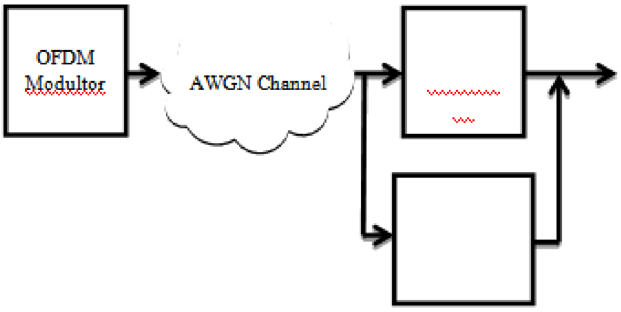

Figure-3. A simple OFDM system.

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

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

The AWGN noise $n_{\boldsymbol{awgn}(i)}$is proven to be identically independent 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. $\{b_n(t) * n_{\boldsymbol{awgn}}(t)\}$.

At the receiver, the data obtained is y(n) along with noise. The serial data obtained is converted to parallel using a serial to parallel converter. The cyclic prefix added is then removed. The data behind removed cyclic prefix is performed DFT, which is estimated with channel co-efficient, converted back to serial data and output is obtained.

3. CHANNEL ESTIMATION IN OFDM

The Channel estimation in OFDM can be performed by either inserting pilot tones into all of the sub-carriers of OFDM symbols or inserting pilot tones into each OFDM symbol. The former case is known asblock type pilot channel estimation and is best suitable in suitable in slow fading channel. The estimation of block type pilot arrangement may be using Least Square (LS) or Minimum Mean Square error (MMSE) algorithm. MMSE estimates prove better than LS estimate with 10-15 dB gain in SNR for the MSE. In [15-3], linear MMSE is performed with low- rank approximation by using frequency correlation of channel to eliminate the primary drawback of MMSE, which is complex. As mentioned earlier, the comb type channel estimation satisfies its performance even in fast fading channel, it has algorithm to estimate the channel at pilot frequencies and to interpolate the channel. In [1], modified time domain ML estimation explains its performance is profitable when the number of pilot sub-carriers is small and is allocated in comb type pilot arrangement with null sub-carriers. In [17] uneven comb pilot based channel estimation justify with scattered data interpolation algorithm showing Radial

Basis Function (RBF) is better than spline and LaGrange interpolation at 5dB SNR. Here, we used the Block-type pilot channel for satisfying the need of equalization when the channel changes from one OFDM block to another one subsequent OFDM block. Since it tracks fast fading channels and performs better.

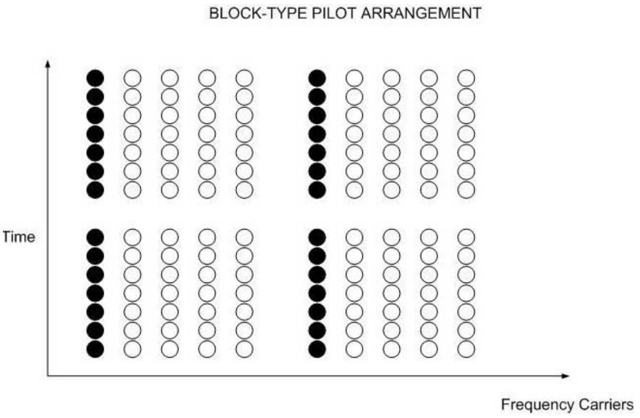

Figure-4. Block type pilot arrangement.

3.1. 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 easy and probability function is not required for determining the channel response [4].

Let 'k' be the channel vector response, then LS estimation of the channel can be approximated as

$$\widehat{g_{Ls}} = E L_{Ls} E^K X^K y \tag{12}$$

Where L_{Ls} can be written as

$$L_{Ls} = (E X E^K X^K)^{-1} \tag{13}$$

The LS channel vector estimation 'k' is given by

$$\widehat{g_{Ls}} = X^{-1} y \tag{14}$$

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

$$\widehat{g_{Ls}} = T\, L'_{Ls} T^K X^K y \tag{15}$$

Where L'_{Ls} is written as

$$L'_{Ls} = (T\, X\, T^K X^K)^{-1} \tag{16}$$

3.2. Minimum mean square channel estimation (MMSE)

Comparing with LS, MMSE performs better, since it uses the information of Signal to Noise Ratio (SNR) and channel characteristics, to estimate the channel. Compared to LS, MMSE complexity is more. But by assuming the flat response of Power Delay Profile (PDP) and finite length sequence, complexity in MMSE can be reduced and improves the performance [4].

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

$$\widehat{g_{MMSE}} = r_{kx} {r_{xx}}^{-1} x \tag{17}$$

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

$$r_{kx} = r_{kk} F^k Y^k \tag{18}$$

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

$$r_{xx} = Y F r_{kk} F^k Y^k + \sigma^2 I_n \tag{19}$$

The response of Channel estimation in frequency domain is given by

$$\widehat{g_{Ls}} = F\hat{h} = F L Y^K F^K x \tag{20}$$

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

$$L = r_{xx}[(FY\, F^K Y^K)^{-1}\sigma^2 + r_{xx}]^{-1}(FY\, F^K Y^K)^{-1} \tag{21}$$

The LS estimate is susceptible to InterCarrier Interference (ICI) noise. To compromise complexity, the MMSE Channel Estimation is proposed. At each of its iteration, MMSE includes the matrix inversion. This matrix version is simplified version and this is calculated only once. The low-rank approximation by using singular value recombination is used to reduce the complexity.

4. RESULTS AND DISCUSSIONS

The simulation is carried out using MATLAB with signal processing toolbox. This paper simulates the OFDM signal transmission based on the specification parameters listed as per the data in the Table-1 which is referred from IEEE 802.11a timing parameter. The paper carries OFDM transmission for 64 subcarriers. The modulation carried for OFDM transmission is QAM with N=4 and hence 16 QAM. Though we studied about different pilot arrangement, here pilot type arrangement is followed. And we compare those results from MATLAB and LABVIEW.

Table-1. Simulation parameters for time domain channel estimation in OFDM systems.

Parameters	Specification
Number of subcarriers used	64
OFDM symbol bandwidth	20 MHz
Subcarrier frequency spacing	0.3125 MHz
Number of used subcarriers	52
Number of data subcarriers	48
Number of pilot/CP length	8
FFT size	64
OFDM symbols	256
Modulation scheme used	16-QAM
Channel model	AWGN

First the work was started with best suitable modulation scheme for OFDM. In view of this, QAM is chosen, in which the simulated BER shows equivalent theoretical results. Then the BER analysis for different modulation scheme is chosen. Finally BER analysis of OFDM transmission and reception with and without channel estimation is shown.

The Figure-5 describes the received OFDM signal at the receiver given as input for QAM modulator and QAM demodulator provides the OFDM signal output.

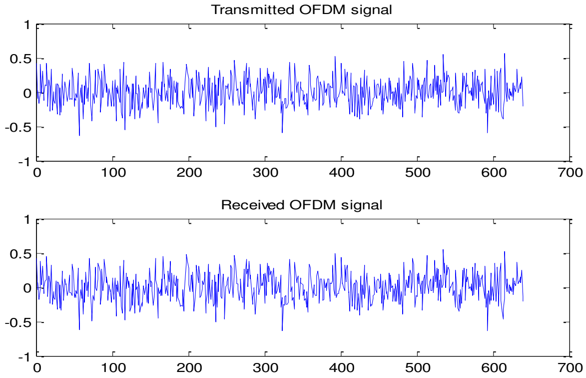

Figure-5. Transmitted and received OFDM signal.

The following Figure-6 shows the simulation curve for BER of QAM using OFDM with simulated result and theoretical result.

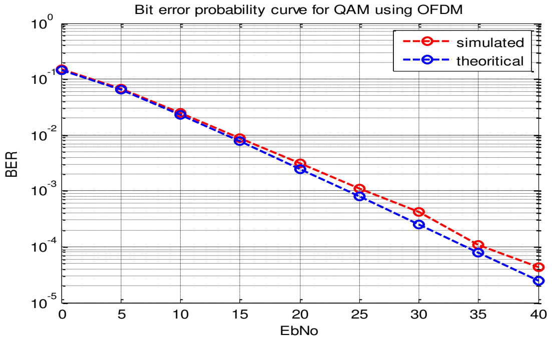

Figure-6. BER of QAM signal.

The following Figure-7 shows the BER vs. E_b/N_0 for QAM modulation scheme with different 'n' values. It is observed that BPSK and 4-QAM has same result, whereas there is a 4 dB difference for every QAM. The D-QPSK has better performance of 6 dB improvement than 64 QAM.

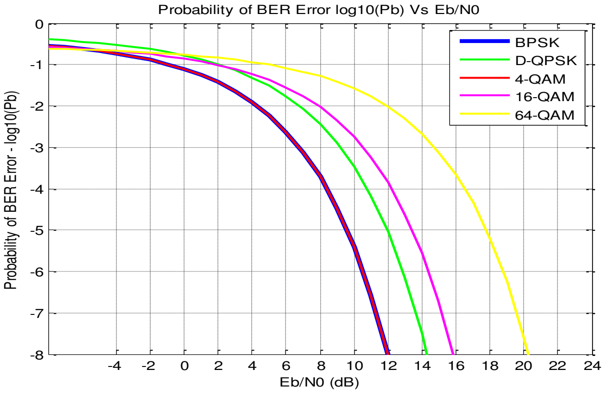

Figure-7. BER of different modulation schemes.

Figure-8 shows the bit error rate of the received OFDM signal with and without channel estimation. Without channel estimation we could observe that BER is better than BER with channel estimation. It is observed at error rate of 10^0upto 33 dB gain is achieved for channel estimation over non-channel estimation This is because the channel is fast fading channel and is responsive to any significant variation with channel conditions.

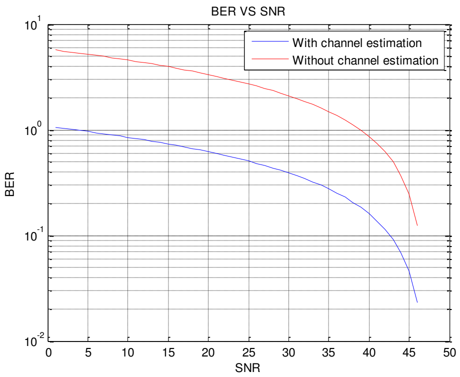

Figure-8. BER Vs SNR for with and without channel estimation.

CONCLUSIONS

In this paper, OFDM transmission scenario with and without channel estimation is compared for bit error rate performance. And the simulation results show SNR is better for OFDM transmission over slow varying channel with 33dB gain over fast varying channel environment. Further it is observed the chosen pilot symbol arrangement namely block type suits well for the above performance. Our future work lies in estimating the channel based on non-parametric method of power spectrum methodology.

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