Survey on Channel Estimation of the Orthogonal Frequency Division Multiplexing

Aswani Lalitha, G.Harinatha Reddy

ABSTRACT--- Orthogonal Frequency Division Multiplexing (OFDM) system is significantly used in several communication devices such as smart phones, television, radio, and so on. Nowadays, OFDM is the most important system for effective communication in wireless domain. In communication systems, the Channel Estimation (CE) plays a major role in finding the characteristics of the channel based on the received data value. In order to manage the communication data, most of the researchers focused on the CE by using different techniques like Minimum Mean Square (MMSE), Least Square (LS), blind, semi-blind and also developed new methodologies for the OFDM. This survey paper summarizes previous research works based on the CE algorithms of OFDM and also examined the major limitations of those techniques. This paper will help the researchers about the present drawbacks in the OFDM system.

Keywords: Channel estimation, Communication system, Internet, Orthogonal Frequency Division Multiplexing.

1. INTRODUCTION

In the present days, the OFDM is mostly used in wireless communication system because of its High Rate Transmission (HRT) capacity with efficiency bandwidth [1] . The OFDM has been significantly employed in the digital Audio Broadcasting Systems (ABS) and Video Broadcasting System (VBS), digital subscriber line standards, wireless communication standards (HiperLAN2, 802.16 WiMAX) in Europe, and Australia [2], [3]. The differential Phase Shift Keying (PSK) in OFDM systems is avoided because of time-varying channel. But, it limits the number of bits/symbol. The Coherent Modulation System (CMS) allows the arbitrary signal constellations, but effectiveness of the CE strategies are needed for coherent detection and decoding. The OFDM is a promising technique for long-haul communication systems due to its more spectral efficiency and robustness against polarization, mode dispersion and chromatic dispersion [4], [5]. However, the long symbol period of the OFDM is sensitive to laser phase noise. The laser phase noise generates both inter-carrier interference and Common Phase Error (CPE), which reduces the performance of the system. Hence, it is significant to estimate and compensate the CPE [6]. Several research works were carried out for enhancing the efficiency of CE of OFDM, but still these methods are not able to achieve satisfactory results in retrieval performance.

Generally, there are two major problems in channel estimator design for wireless OFDM systems. Arrangement of the pilot data is one of the problem, where the pilot denotes the reference signal employed by Receivers (Rx) and Transmitters (Txs). The design of estimator with better channel tracking capability, and low complexity is second problem. [7]. The CE is used for block type pilot arrangement based on MMSE, LS CE techniques [8] [9]. The MMSE based CE produce 10 to 15 dB gain in signal to noise ratio for the same Mean Square Error (MSE) of CE over LS estimate [10]. Low-rank approximation applies to the linear MMSE by employing Frequency Correlation (FC) of the channel to neglect limitation of MMSE technique that have high complex [11] [12]. In the OFDM system, the CE is an important aspect of retrieval technology and also the correlation is measured to maximize the efficiency of the OFDM system. In this work, a detailed survey on CE for OFDM was done in order to analyze the performance and problems of the existing technologies. This will motivate the researchers for further research work in the CE technique for OFDM.

2. OVERVIEW OF THE CE IN OFDM

Generally, the fading channel of OFDMs is viewed as a Two-Dimensional (2D) signal (Frequency and Time). The optimal CE in terms of MSE is based on 2D wiener filter interpolation. Unfortunately, a 2D estimator structure is more complex for practical implementation. The combination of large data rates and low Bit Error Rates (BERs) in OFDM systems requires an estimator that has more accuracy and low complexity where the two constrained work against each other and a good trade-off is required. One-Dimensional (1D) CE is adopted in the OFDM system to accomplish the trade-off between accuracy and complexity [13]. There are two kinds of 1D channel estimators such as block-type CE, and comb-type CE available, where the pilots are inserted in the frequency/time direction. The block-type pilots arrangement consists of MMSE, modified MMSE, and LS [14] [15]. The comb-type pilot arrangement includes maximum likelihood estimators, Parametric Channel Modelling Based Estimator (PCMB) [16] [17]. The CE techniques categorize as semi-blind CE [18], blind CE [19], Pilot Aided (PA) CE [20]. The blind CE performs CE by utilizing the statistics of received data, virtual carriers, cyclic prefix, and received diversity. The blind estimations require the channel to be constant for a huge number of blocks. So, the blind CE approach is not suitable for highly mobile applications. The topmost communication standards such as Long-Term Evolutions (LTEs) and digital video broadcasting increase the system efficiency using the pilot CE techniques. In large mobility

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CE, each stage has individual challenges and features due to a long time dispersion, and the fast time-variation of the channels.

2.1. General procedure for the Channel Estimation

Presently most of the communication systems require CE for symbol detection and equalization process. It improves by employing dedicated pilot symbol, which consumes a non-negligible part of power resources and throughput for huge dimensional device/system. The LS approach based CE technique is most suitable for other optical OFDM systems. The physical Visible Light Communication (VLC) channel scheme includes diffuse elements and line of sight (LOS) [12]. The channel impulse response from the i^{th} Light Emitting Diode (LED) to the k^{th} user is given in equation (1),

$$c_{(k,i)}(t) = \eta(k,i).LOS\delta(t) + c_{(k,i)}, diffuse\ (t - \nabla_{\tau}(k,i)) \tag{1}$$

Here, $\eta(k,i)LOS$ represents the LOS elements, i^{th} represents Dirac Delta Function (DDF), $c_{(k,i)}, diffuse$ is diffusion element, $\nabla_{\tau}(k,i)$ represents delay between the diffuse and LOS signal. In the discrete time domain, the channel impulse signal from the i^{th} LED to k^{th} the user is shown in equation (2),

$$h_{(k,i)}(n) \overset{\Delta}{=} c_{(k,i)}(nT_S) \tag{2}$$

Here, the sampling interval denote as T_S. The input of LEDs signal must be real or non-negative. Thus, the signal in the frequency domain of i^{th} LED should be Hermitian symmetric, which represented in equation (3),

$$\begin{Bmatrix} x_i(K) = X_i^*(N-K) \\ X_i(0) = X_i(\frac{N}{2}) = 0 \end{Bmatrix} \tag{3}$$

Here, N represents a sum of sub-carriers. The (Rx) signal of k^{th} user is given in equation (4),

$$y_k(n) = \sum_{i=1}^{N_t} h_{(k.i)}(n) \otimes (x_i(n) + DC_i) + \omega_k(n) \tag{4}$$

Where, $x_i(n)$ is the time domain expression, DC_i represents DC bias additional at the i^{th} LED, Noise Component (NC) at receiver of k^{th} user represented as $\omega_k(n)$. Next deleting the cyclic prefix, then taking Fast Fourier Transform (FFT) of $y_k(n)$, the frequency domain signal is expressed in equation (5),

$$y_k(K) = \sum_{i=1}^{N_i} H_{(k.i)}(K)\, X_i(K) + W_k(K) \quad K > 0 \tag{5}$$

Here, the signal $y_k(K)$ can rewrite in the vector form, it is given in equation (6)

$$y_k = \sum_{i=1} diag\{X_I\} H_{(k,i)} + W_k$$

$$y_k = \sum_{i=1}^{N_i} diag\{X_I\} Fh_{(k,i)} + W_k \tag{6}$$

Here, T is transpose operation $diag\{.\}$ represents a diagonal operation, $H_{(k,i)} = [H_{(k,i)}(1), H_{(k,i)}(2), ...H_{(k,i)}(N-1)]^T$ and $h_{(k,i)} = [h_{(k,i)}(1), h_{(k,i)}(2), ...h_{(k,i)}(L-1)]^T$. L is the channel length, F is initial L columns of the FFT T matrix except for the initial row that assumes N_P pilot tones used for the CE. Define a set of pilot tone indices given in equation (7),

$$Z_p = \left\{ k_0 + l.N_I, l = 0,1,2,... {}^{N_P}\!/\, 2-1 \right\} \tag{7}$$

Here, $k_0 \in \{1, ...N_I - 1\}$ represents the initial Pilot Tone Position (PTP), and N_I is PT interval period of the Z_P. The group of pilot tone indices in DC-biased optical OFDM based on VLC to satisfy Hermitian scheme, it is defined in equation (8),

$$\Omega_P = \{ K/K \in Z_P \} \tag{8}$$

The OFDM pilot symbol is only carry pilots. Example for the CE is given in equation (9),

$$Y_k^{(p)} = \sum_{I=1}^{N_i} diag\{P_I\} H_{(k,i)}^P + H_{(k,i)}^p$$

$$Y_k^{(p)} = \sum_{I=1}^{N_i} A_i Eh_{(k,i)} + W_K^{(P)} \tag{9}$$

Here, P_i represents pilot order vector of i^{th} LED, $A_i = diag\{P_i\}$, $H_{(k,i)}^p$ are represents channel vector, noise vector to pilot tone. E Contains rows of them F.

2.3. Pilot Based Channel Estimation

The training symbols are well known to the receiver that multiplied with the data stream in pilot based CE. The pilot based CE is two types block-type and comb type CE. In the block type CE technique, training symbols are inserted into whole frequency bins with a periodic time of the optical OFDM blocks, which suits for a slow fading channel. The comb-type CE technique is used for the fast fading channel

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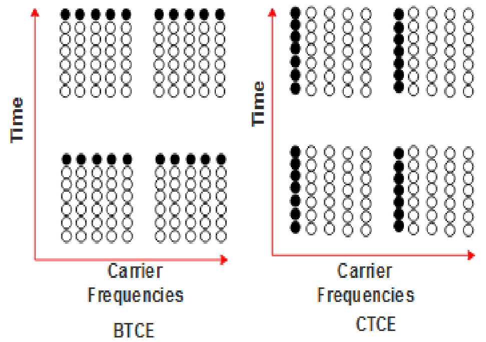
where the channels changes between adjacent OFDM, the pilots are transmitted at all times with similar spacing on the subcarrier representing a comb type CE placement. The fig.1 shows the diagram of the block and comb type CE technique based pilot arrangement.

3. RESULTS



4.

Figure.1 Diagram of the block and comb type CE technique based pilot arrangement.

2.3.1. Block Type Channel Estimation

The channel conditions are estimated by the given transmitted pilot signals and received signals, with or without employing the certain idea of the channel statistics. The receiver signals utilize the estimated channel conditions to decode the receiver data with block until the next pilot symbol arrives. The block type pilot scheme includes LS, and MMSE techniques.

2.3.1.1. Least Square Channel Estimation

The LS technique uses statistical data in the channel frequency response. In the White Gaussian Noise environment, it is easy to produce the LS estimation value which is equivalent to the maximum likelihood estimation. For conventional CE problem, the maximum likelihood CE is the optimum method that improves the Cramer Rao Bound (CRB) performance. The LS-CE reduces the parameter $(\overline{Y}-\underline{X}\,\overline{H})^H(\overline{Y}-\underline{X}\,\overline{H})$, here $(.)^H$ denotes the Conjugate Transpose Operation (CTO), which is shown in the equation (10),

$$\hat{H}_{LS} = \underline{X}^{-1}\overline{Y} = [{}^{X_k}\!/\!{}_{Y_k}]^T \quad (k = 0,1,2,...N-1) \tag{10}$$

From equation (10), the MSE is inversely proportional to Signal to Noise Ratio (SNR). It may be focus to noise enhancement when the channel is in a deep null because of its easiness [21] [22].

2.3.2.2. Minimum Mean Square Channel Estimation

The MMSE estimator is the second order statistics of the channel conditions to reduce the MSE value [23]. The $\underline{R}_{gg}$, $\underline{R}_{HH}$, and $\underline{R}_{YY}$ is the auto-covariance matrix of $\overline{g}$, $\overline{H}$, $\overline{Y}$. By $\underline{R}_{gY}$, the σ_N^2 is noise variance, $\overline{g}$ represents channel vector, noise $\overline{N}$ is uncorrelated, it is described in equation (11.)

$$\underline{R}_{HH} = E\{\overline{H}\,\overline{H}^H\} = E\{(\underline{F}\overline{g})(\underline{F}\overline{g})^H\} = \underline{F}\,\underline{R}_{gg}\underline{F}^H \tag{11}$$

$$\underline{R}_{gH} = E\{\overline{g}\,\overline{Y}^H\} = E\{(\overline{g}\,\underline{X}\,\underline{F}\,\overline{g}+\overline{N})^H\} = \underline{X}^H\underline{R}_{gg}\underline{F}^H \tag{12}$$

$$\underline{R}_{YY} = E\{\overline{Y}\,\overline{Y}^H\} = \underline{X}\,\underline{F}\,\overline{R}_{gg}\overline{F}^H\overline{R}^H + \sigma_N^2\underline{I}_N \tag{13}$$

$\underline{R}_{gg}$,and σ_N^2 considered at the receiver, the MMSE estimator of $\overline{g}$ is given by $\hat{g}_{MMSE} = \underline{R}_{gY}\underline{R}_{YY}{}^{-1}Y^{-HH}$. $\overline{g}$ is a not Gaussian, and $\hat{g}_{MMSE}$ is not a minimum MSE estimator. But it is the better estimator in the MSE, given in the following equation (14)

$$\hat{H}_{MMSE} = \underline{F}\hat{g}_{MMSE} = \underline{F}[(\underline{F}^H\underline{X}^H)^{-1}\underline{R}^{-1}{}_{gg}\sigma_N^2 + XF]^{-1}\overline{Y}$$

$$= \underline{F}\,\underline{R}_{gg}[(\underline{F}^H\underline{X}^H\underline{X}\,\underline{F})^{-1}\sigma_N^2 + \underline{R}_{gg}]\underline{F}^{-1}\hat{H}_{LS} \tag{14}$$

The MMSE based CE provides better performance than LS based CE under low-SNR. The major limitation of the MMSE-CE is more computational complexity.

2.3.2. Comb Type Channel Estimation

The CE problem in the OFDM systems with transmit diversity has considered. The CE is based on combo type pilots in the frequency domain, it can produce high bandwidth efficiency compared to training block pilots. The combo type pilot scheme including maximum likelihood CE and PCMB- CE.

2.3.2.1. Maximum Likelihood Channel Estimation

In Maximum Likelihood Estimator (MLE), the energy in $\overline{g}$ has in, or near, the first $(L+1)$ taps which are similar to the modified MMSE estimator, where $L = \left[T_G / T_S\right]N$. The first $(L+1)$ taps of $\overline{g}$ is $\overline{g}_{L+1} = [g_0,....g_{L+!}]^T$. The non-square DFT matrix is defined for the definition of the square DFT matrix [25], [26] which is shown in equation (15)

$$\underline{F}_{A,B} = [W_N{}^{a,b}]_{A\times B} \qquad (0 \le a < A, 0 \le b < B) \tag{15}$$

The uniform spaced DFT matrix is also defined with space S which is given by the following equation (16)

$$\underline{F}(S)_{A,B} = [W_N{}^{aS,b}]_{A\times B} = [W_N{}^{a,bS}]_{A\times B} \qquad (0 \le a < A, 0 \le b < B) \tag{16}$$

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It is obvious that $\overline{H}^{p} = \underline{F}(S)_{Np\times(L+1)}\overline{g}_{L+1}$. Where S is the space among the pilot subcarriers. Then the MLE ($\overline{g}_{L+1}$) is the estimate $\overline{H}p$ is obtained by following equation (17).

$$\overline{g}_{L+1} = (\underline{F}(S)^{H}_{Np,(L+1)} \times \underline{F}(S)_{Np,(L+1)})^{-1}(\underline{F}(S)^{H}_{Np,(L+1)})\hat{H}^{P}_{LS} \quad (17)$$

At last, the complete channel estimate $\hat{H}$ of all subcarriers is computed from $\overline{g}_{L+1}$ and $\hat{H}$ of maximum likelihood based CE is expressed in equation (18).

$$\hat{H}_{MLE} = \underline{F}_{N,(L+1)}\hat{g}_{L+1} \quad (18)$$

2.3.2.2. Parametric Channel Modelling Based Channel Estimation

The modelling of the channel depends on the Multipath Fading Channel (MFC) with M resolvable paths with various path complex gain $\{\alpha_m\}$ and time intervals. Assume, the various path gains are uncorrelated which is related to each other and represented by $R_\alpha(M)$ (i.e., channel auto-covariance matrix), where $R_\alpha(M) = diag\{\sigma^2_{\alpha 1},....,\sigma^2_{\alpha M}\}$. This CE $\{\tau_m T_S\}$ scheme is based on the parametric channel. The PCMB estimator requires the knowledge of M and $\{\tau_m T_S\}$. The estimation of M is carried out based on minimum description length. The initial multipath time delays acquired by the estimation of signal parameters by rotational invariance and the channel multipath delays are obtained by inter-path interference delay cancellation loop. The two non uniform spaced DFT matrices are defined in the following equations (19) and (20).

$$\underline{B}_{Np,\hat{M}} = [W_N^{P(k),\hat{\tau}(m)}]_{Np\times\hat{M}} \quad (0 \le k \le N_p, 1 \le m \le \hat{M}) \quad (19)$$

$$\underline{B}_{N,\hat{M}} = [W_N^{i,\hat{\tau}(m)}]_{N\times\hat{M}} \quad (0 \le i \le N_p, 0 \le m \le \hat{M}) \quad (20)$$

Here the pilot locations and multipath time delays are represented as $P(k)$ and $\{\hat{\tau}_m\}$ respectively. The MMSE estimator is given in equation (21).

$$\hat{H}_{PCMB} = \underline{B}_{Np,\hat{M}} \times \left(\frac{\gamma}{SNR} R_\alpha(\hat{M})^{-1} + \underline{B^H}_{Np,\hat{M}}\underline{B}_{Np,\hat{M}}\right)^{-1} \times \underline{B}_{Np,\hat{M}} \times \hat{H}^{P}_{LS} \quad (21)$$

The performance of PCMP and MLE is almost equal though performs slightly better in the MSE at low SNR [27], [28].

2.4. Blind and Semi-Blind Channel Estimation

The blind CE employs the statistical data of the received symbols. In the blind CE, the training arrangement is not required [29]. The blind CE techniques are classified into two types, statistical estimation, and deterministic estimation. The statistical estimation uses an orthogonal vector between the noise and channel subspace vector, it is known as sub-space technique. The Eigen value decomposition of an auto-correlation matrix of the received signal is required in the blind CE algorithm in order to find the noise subspace matrix. The deterministic estimation technique employs the property of the limited alphabet to the symbol, which converges faster than statistical estimation. The major advantage of blind CE is that it consumes high-level of bandwidth, but it is limited to slow time-varying channels, and more complex in the transceiver [30]. The semi-blind CE technique is the hybrid combination of data aided. The blind CE uses pilots and natural constraints to perform the CE. In another way, a number of antennas at the transmitter and receiver increase the complexity of blind CE technique. The pilot based CE techniques used for the slow varying channels. Several types of researchers presented the semi-blind CE technique to solve the drawback of the pilot and blind CE techniques. The semi-blind CE technique achieved better performance and improved accuracy compared to pilot/blind CE techniques [31], [32].

In communication systems, the CE plays a major role in finding the characteristics of the channel based on the received data value. The blind based CE schemes are high system computational complexity and very complex to implement. The pilot based CE schemes are easy to implement but that mitigates the bandwidth efficiency. Nowadays, this pilot based schemes are wide popular, which is significantly supported to the IEEE 802.16e and 3GP LTE standards.

5. LITERATURE SURVEY

The researchers suggested several methodologies for OFDM in the CE. A brief evaluation of some significant contributions to the existing methods are presented in this section.

Author	Methodology	Advantage	Limitation	Performance Measure
Wu *et al*, [33]	Discrete Cosine Transform (DCT) CE technique.	It does not increase the power overhead due to that this method achieved high spectral efficiency	The performance of the system degraded when the power increases	Power value, polarization loss, and estimation error

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Fang *et al*, [34]	Time-domain maximum likelihood CE technique	This has a better overhead reduction and enhanced tolerance against laser phase noise	This research work considered only time domain based CE, which is not much suitable for frequency domain CE.	Polarization, chromatic mode dispersion, and noise level
Qian *et al*, [35]	Zero correlation based CE technique	It has best channel frequency response MSE and BER performance than the LS-CE method	This paper didn't present any block diagram on proposed methodology. Hence, the researchers do not easily understand proposed work.	BER, and MSE
Travaux*et al*, [36]	MMSE technique based CE	The complexity of the system reduced using a low-rank approximation method in the proposed technique	This method increased the BER which degraded the system performance	BER
Nhan*et al*, [37]	Sparse preamble CE technique used for polarization deviation multiplexed coherent OFDM	This method achieved less BER. Hence, that method improved significant gain	The performance of the system was affected by the phase noise when fibre nonlinear signals were degraded.	BER, and Peak to Average Power Ratio (PAPR)
Pallaviram Sure *et al*, [38]	Large random matrix based CE for multiple inputs and multiple outputs -OFDM uplink	This method provided better MSE performance.	This method requires more area	MSE, and SNR
Jinfeng Tian *et al*, [39]	The blind CE based on Time-Varying Autocorrelation Function (TVACF)	This method achieved a significant performance gain in low SNR regime.	The proposed method requires more execution time.	SNR
Batavia *et al*, [40]	LS based on CE by using block type pilot sequence	It allows more accurate representation of high mobility which is the major advantage of the pilot sequence method.	If the system speed increases, it leads to the performance degradation in the LSCE technique	BER and error signal detection
Zhao *et al*, [41]	Weighted inter-frame averaging based CE	The Error Vector Magnitude (EVM) performance of proposed method was 2.4 dB better compared to traditional LS technique under -6 dBm launched power.	It may be not suitable for higher communication applications because the highly information loss	Error vector magnitude, and power, estimation accuracy

The performance of block type and comb type CT pilot techniques are made for the effective transmission of data in OFDM. The CE is necessary in the OFDM for enhancing its BER performance against the impairments of multipath fading channel.

6. CONCLUSION

The CE is one of the significant processes in wireless communication system. The CE algorithms used for OFDM system provides better solutions to the increasing demands of high data rate communications and high quality. In the present days, several works are to be implemented on CE in OFDM system for delivering best retrieval outcome. This paper gives a survey of CE for OFDM system and also evaluates the developed technologies based on advantages, disadvantages and performance measures. In this paper, a brief survey of different CE techniques is presented for OFDM system and their performance is studied. This paper concludes that the performance of different CE techniques based on various power factors, estimation accuracy, BER, error signal detection, SNR and MSE. This survey paper will help readers to understand the conventional CE in OFDM system and enables more meaningful work.

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