A REVIEW BASED ON CHANNEL ESTIMATION FOR OPTICAL - ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

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ABSTRACT

Optical - Orthogonal Frequency Division Multiplexing (OFDM) system generally employ in several communication devices such as telephone, radio, television, internet and so on. In the present days, the optical OFDM is one of the significant methods for an effective communication system. In communication technique, the channel estimation 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 channel estimation by using different techniques like Minimum Mean Square (MMSE), Least Square, blind, semi-blind and also developed new methodologies in the coherent optical OFDM. This review paper analysed the research works based on the channel estimation algorithms of an optical OFDM and also examined the major limitation of these techniques. This paper will help the researchers to give a better solution for the present drawbacks in the coherent optical OFDM system.

Keywords: Channel estimation, Genetic algorithm, Optical-orthogonal frequency division multiplexing, Visible light communication.

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1. INTRODUCTION

The optical OFDM is a multicarrier transmission technique that transmit the data with low-rate subcarrier tones. OFDM has been significantly studied in the mobile communication to combat the hostile frequency selective fading and incorporated into wireless communication standards (HiperLAN2, 802.16 WiMAX digital audio and video broadcasting (DVB-T, and DAB) in Europe, and Australia [1]. Presently, an equivalent optical-domain multi-carrier

format known as coherent OFDM [2], considered as a promising technique for long-haul optical communication systems due to its more spectral efficiency and robustness against polarization mode dispersion and chromatic dispersion [3], [4]. However, the long symbol period of the coherent OFDM is sensitive to laser phase noise. The laser phase noise generates the 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 [5]. Several research work carried out for enhancing the efficiency of optical channel estimation of coherent OFDM, but still these methods not able to achieve satisfactory results in retrieval performance. In recent years, researcher used different techniques to compensate the CPE in OFDM system. The conventional compensation techniques are 2-types: analog techniques based on Radio Frequency (RF) pilots and digital technique based on pilot subcarriers.

The RF pilot technique has achieved less spectral efficiency due to frequency guard band and power overheads. The pilot subcarrier does not require more overhead, but it needs time to coverage and commonly has the cycle slip problem, which degrades the laser phase tolerance [6]. The channel estimation is used for block type pilot arrangement based on MMSE or LS channel estimation techniques. The MMSE based channel estimation produce 10 to 15 dB gain in signal to noise ratio for the same Mean Square Error (MSE) of channel estimation over LS estimate [7]. A low-rank approximation applies to the linear MMSE by employing frequency correlation of the channel to neglect the major limitation of the MMSE technique, which is more complex [8]. Optical line components like coupler, switch, erbium-doped fiber amplifier, and isolator gets affected by the Polarization Mode Dispersion (PMD) which causes a non-negligible error in the optical OFDM. System performances affect by various parameters such as, Optical Signal to Noise Ratio (OSNR), Bit Error Rate (BER) and MSE. There are several re-portable approach is used to estimate the common section error in optical OFDM system [9] [10]. In optical OFDM system, channel estimation is the most important aspect of retrieval technology and also the correlation are measured to increase an efficiency of the research process to the optical OFDM system. In this paper, a detailed review on the channel estimation for optical-OFDM has done in order to analyse the performance and problems of the existing technologies. This process motivates the researchers for further research work in channel estimation technique for optical OFDM.

2. OVERVIEW OF THE CHANNEL ESTIMATION FOR OPTICAL OFDM

Channel estimation techniques commonly categorize as semi-blind, blind, Pilot Aided (PA) channel estimations. The blind channel estimation performs by utilizing the statistics of received data, virtual carriers, cyclic prefix, and received diversity. That blind estimations commonly require the channel to be constant for a huge number of blocks. So, the blind channel estimation approach is not suitable for large mobility applications. The topmost communication standards such as Long-Term Evaluations (LTEs) and digital video broadcasting has increased the system efficiency by using the pilot channel estimation techniques. In large mobility channel estimation, each stage has individual challenges and features due to a long time dispersion, and the fast time-variation of the channels [11].

2.1. General procedure for the Channel Estimation

Presently most of the communication systems require channel estimation 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 channel estimation 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 expressed in Eq. (1),

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

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

$$h_{(k,i)}(n) \stackrel{\Delta}{=} c_{(k,i)}(nT_s) \quad (2)$$

Where, T_s represents the sampling interval. In the intensity modulation of DD VLC [13], the signal fed to LEDs must be real and non-negative. Thus, the signal or tone in the frequency domain of i^{th} LED must be Hermitian symmetric as represented in Eq. (3),

$$\left\{ \begin{array}{l} x_i(K) = X_i^*(N-K) \\ X_i(0) = X_i(\frac{N}{2}) = 0 \end{array} \right\} \quad (3)$$

Here, N represents total number of sub-carriers. The received signal of k^{th} user is expressed in Eq. (4),

$$y_k(n) = \sum_{i=1}^{N_L} h_{(k,i)}(n) \otimes (x_i(n) + DC_i) + \omega_k(n) \quad (4)$$

Where, $x_i(n)$ is the Time domain expression of $X_i(K)$, $\otimes$ standard convolution, DC_i represents DC bias added at the i^{th} LED, $\omega_k(n)$ denotes the noise component at the receiver of k^{th} user. Next deleting the cyclic prefix, then taking Fast Fourier Transform (FFT) of $y_k(n)$, the frequency domain signal is expressed in Eq. (5),

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

Here, $H_{(k,i)} = FFT\{h_{(k,i)}(n)\}$, $W_k(K) = FFT\{\omega_k(n)\}$, and $FFT\{\cdot\}$ represents FFT operation. The signal $y_k(K)$ can be rewrite in the vector form is expressed in Eq. (6)

$$y_k = \sum_{i=1}^{N_L} diag\{X_i\} F h_{(k,i)} + W_k \quad (6)$$

Here, $y_k = [Y_k(1), Y_k(2), \dots, Y_k(N-1)]^T$, T denotes the transpose operation. $X_i = [X_i(1), X_i(2), \dots, X_i(N-1)]^T$, $diag\{\cdot\}$ represents diagonal operation, $H_{(k,i)} = [H_{(k,i)}(1), H_{(k,i)}(2), \dots, H_{(k,i)}(N-1)]^T$, and $W_i = [W_i(1), W_i(2), \dots, W_i(N-1)]^T$, $h_{(k,i)} = [h_{(k,i)}(1), h_{(k,i)}(2), \dots, h_{(k,i)}(L-1)]^T$, here L - represents length of the channel, F - denotes the first L columns of the FFT T-matrix except the first row, which assume N_p pilot tones for the channel estimation. A pilot tone indices are similar for all transmit LED. Describe a set of pilot tone indices expressed in Eq. (7),

$$Z_p = \left\{ k_0 + l \cdot N_L, l = 0, 1, 2, \dots, \frac{N_p}{2} - 1 \right\} \quad (7)$$

Here, $k_0 \in \{1, \dots, N_L - 1\}$ represents the first pilot tone position, N_L denotes pilot tone interval period of the Z_p . To satisfy Hermitian scheme, the group of pilot tone indices in DC biased optical OFDM based on VLC is defined in Eq. (8),

$$\Omega_p = \{K/K \in Z_p\} \quad (8)$$

In OFDM pilot symbol, the pilots occupy the specific subcarriers that include pilot tones, and other sub-carriers can be employed to Carry Information Data (CID), it will degrade the power of received signal. Next, the channel estimation of every user will be sent back to a transmitter used for Zero Forcing (ZF) pre-coding. Hence, it is expected that the OFDM pilot symbol will only carry pilots, no data will be carried in the OFDM pilot symbol. Example for the channel estimation is given in Eq. (9),

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

$$Y_k^{(p)} = \sum_{I=1}^{N_I} A_i E h_{(k,i)} + W_K^{(P)} \quad (9)$$

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

2.2. Data-Aided Channel Estimation (D-ACE)

The fig.1 shows the diagram of common pilot symbols and pilot subcarriers sequence. The D-ACE technique send the pilot sequence to the preamble of each data set, and apply to the various kinds of channels, even though the pilots degrades the data ratio. One of the channel estimation technique done by employing pilot symbols as a reference signal. The pilot symbols do not carry information, but it is known in both transmitter and receiver.

Figure 1 Diagram of common pilot symbols and pilot subcarriers sequence

The characteristic of the estimated channel technique to the real value offers a better reference signal to create an equalization at the receiver. In the D-ACE technique, known information to receiver is inserted in the optical OFDM symbol so that current channel can be estimated. The previous data arrangement is known as channel estimation. That channel estimation with training symbols is called as Pilot-Aided Channel Estimation (PACE).

2.2.1. Pilot based channel estimation

In the pilot based estimation technique, the training symbols known to the receiver is multiplexed with the data stream. The pilot channel estimation method uses an idea of the transmitted pilot symbols at the receiver to estimate the channel. The extra pilot symbol with the particular pilot pattern employ for the channel estimation, which is called as pilot based channel estimation.

Figure 2 Diagram of pilot based channel estimation technique like BTCE, and CTCE method

The pilot based channel estimation is classified into two types Block Type Channel Estimation (BTCE) and Comb Type Channel Estimation (CTCE). In the BTCE technique, training symbols insert into whole frequency bins with periodic time of the optical OFDM blocks, which suits for a slow fading channel. The CTCE technique is used for the fast fading channel where the channels changes between adjacent optical OFDM, the pilots are transmitted at all times with similar spacing on the subcarrier representing a CTCE placement. The fig.2 shows the diagram of PTCE and CTCE technique based pilot arrangement.

2.3. Training based LS Channel Estimation (LSCE)

The training symbols are used for the channel estimation which provides a better performance. But, their transmission effectiveness is mitigated due to needed overhead of training symbols like pilot tones. The LS and MMSE approaches mostly use for channel estimation when training symbols are available.

2.3.1. LS Channel Estimation (LSCE)

The LSCE technique utilizes a number of statistical data in the Channel Frequency Response (CFR). In white Gaussian noise, it is easy to deliver the LS estimation value which is equivalent to the Maximum Likelihood (ML) estimation. For traditional channel estimation issue, the ML channel estimation is the optical technique that improves the Cramer Rao Bound (CRB) performance. Since ML estimation approach requires an idea about the channel statistics, because the estimation performances are not better. Moreover, the LSCE technique may affect noise enhancement when the channel matrix has a huge condition number. Channel estimate $\hat{H}$ in the LSCE technique is described by the Eq. (10),

$$\hat{H}_{LSCE}[K] = \frac{A[K]}{B[K]} \quad (10)$$

The MSE of LSCE is given as

$$MSE_{LSCE}^{\wedge} = \frac{\sigma^2 c}{\sigma^2 c} \quad (11)$$

From Eq. (11), MSE is inversely proportional to signal to noise ratio, which may be subject to noise enhancement, when the channel is in a deep null due to its simplicity. However, the LSCE technique has been generally employed for the channel estimation [14].

2.3.2. Training based MMSE channel estimation

Consider the LSCE technique solution in Eq. (10). By employing the weight matrix W , it is defined as $\hat{H} = W\tilde{H}$, which corresponds to MMSE channel estimate as shown in Eq. (12),

$$\hat{H} = W\tilde{H} = R_{\tilde{H}\tilde{H}}^{-1} R_{\tilde{H}H} \tilde{H} \quad (12)$$

Here, $R_{\tilde{H}\tilde{H}}$ is the cross channel matrix function between the temporary channel and true channel vector in the frequency domain [15].

2.4. Blind Channel Estimation (BCE)

The BCE technique use the statistical data of received symbols [16]. The major advantage of BCE is that it consumes high-level bandwidth, but it limited to slow time-varying channels, and more complex at the receiver. The training arrangement not require in the blind technique. The BCE approaches are two types statistical estimation, and deterministic estimation. The statistical estimation employs an orthogonal between the noise and channel subspace vector, it is known as sub-space technique. Thus, the Eigenvalue decomposition of an auto-correlation matrix of the received signal require in the BCE algorithm in order to find the noise subspace matrix. On the other hand, the deterministic technique employs the property of the limited alphabet to the symbol, which converges faster compared to the statistical technique. The main limitation of BCE technique is that it is more complex in the transceiver [17].

2.5. Semi- Blind Channel Estimation (S-BCE)

The S-BCE technique is the hybrid combination of data aided, and BCE technique, which uses pilots and natural constraints to perform the channel estimation. In another way, a number of antennas at the transmitter and receiver increases the complexity of BCE technique. The pilot channel estimation based techniques useful for the slow varying channels. Several types of research presented the S-BCE technique to solve the drawback of pilot and BCE techniques. The S-BCE technique achieves better performance and improve accuracy than pilot/BCE technique [18], [19].

3. LITERATURE WORK

Several techniques are suggested by researchers in the channel estimation used for optical OFDM. In this scenario, brief evaluation of some important contributions to the existing literatures are presented.

Author	Methodology	Advantage	Limitation	Performance measure
Wu et al, [20]	Training symbol used in the optical signal to noise ratio	The method does not require additional overhead; hence the spectral efficiency is not degraded.	This method increased the power at the same time monitoring performance was degraded	Estimation error, power value, and polarization loss
Zhao et al, [21]	New channel estimation technique for fast optical OFDM	This method has a very simple system design which provides better accuracy	The system architecture was more complex when increasing the training sequence	Training performance, bit error rate
Fang et al, [22]	Time domain ML channel estimation technique	This method has better overhead reduction. Also, it has enhanced tolerance against laser phase noise.	This research work considered only time domain channel estimation, which may not be suitable for the frequency domain channel estimation technique.	Chromatic dispersion, polarization mode dispersion, and noise level
Ouyang et	Unbiased channel	This method avoided the	The proposed method	Estimation error

al, [23]	estimation based discrete Fresnel transform	performance degradation due to the dispersion depend on the deviation	was only based on internal- symbol frequency domain, not considered about inter symbol frequency domain	of system error
Qian et al, [24]	Channel estimation based on zero correlation code	This method has better channel estimation and also it reduce the computation complexity compared to LSCE technique	This method only concentrated on two performance parameter such as MSE and Bit Error Rate (BER)	MSE, and BER performance
Savaux et al, [25]	MMSE channel estimation	This proposed method reduced the complexity using a low-rank approximation	This method achieved less spectral efficiency but the BER was high	BER performance
Wu et al, [26]	LS channel estimation of optical OFDM system	This method was optimized for the pilot tones and pilot sequence, hence it achieved less MSE value	The analytical calculation was the main drawback of the proposed	MSE, and BER performance
Yu et al, [27]	Channel estimation based on an individual subcarrier in optical OFDM	This method reduced the inner part constellation because it achieved less complexity	This method was implemented using several modules, which required more area	BER performance
Zhao et al, [28]	Weighted inter-frame averaging based channel estimation	It performed various launched power value	This method only concentrated on power performance	Error vector magnitude, and power, estimation accuracy
Zhang et al, [29]	LSCE technique used for coherent optical OFDM	This method has less complexity because it provided better performance in slow fading channels	If the system speed increases, it leads to the performance degradation in the LSCE technique	MSE and BER performance
Nhan et al, [30]	Sparse preamble channel estimation used for Polarization division multiplexed coherent OFDM	Sparse channel estimation achieved less BER. Hence, that method improved significant gain.	The performance of the system was affected by the phase noise when fiber nonlinear signals were degraded.	BER, and Peak to Average Power Ratio (PAPR)

4. CONCLUSIONS

The channel estimation is the most powerful and effective algorithm for optical OFDM based on multiuser-visible light communication system. The channel estimation provides an enormous different technology for providing better retrieval value, which is used in several applications such as telephone, radio, television, and internet. This review paper provides an overview of the channel estimation based optical OFDM system and evaluates the developed technologies in terms of advantage, disadvantage, and performance measure. From this review work, it is found that the phase noise is the major problem which affect the signal over the channel estimation process. To overcome this problem researcher implemented several advanced techniques based on channel estimation for the optical OFDM.

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