ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 4, April 2014

Attaining an Efficient Coherent Optical OFDM System

N.Sangeetha[1], K.P.Nithin[2], M.Aakash[3]

Assistant Professor, ECE, VIT University, Vellore, India [1]

Student, ECE, VIT University, Vellore, India[2,3]

Abstract: Coherent optical OFDM (CO-OFDM) is a promising technology for the next-generation optical transmission systems beyond 100 GB/s which has been proposed recently and its implementation has shown extreme robustness against chromatic dispersion and polarization mode dispersion. The proposed synchronization method provides better results when compared with Schmidl, Minn and Park's methods in terms of timing and frequency offset estimation. Since CO-OFDM is sensitive to noises, channel estimation plays an important role in detecting baseband data from the received signal. A DFT based channel estimation technique is proposed which gives a better performance when compared to conventional LS and MMSE methods.

Keywords: CO-OFDM, CFO, Channel Estimation, DFT, LS, MMSE, MATLAB, Synchronization, Timing offset

I. INTRODUCTION

In general achieving high data rate, spectral efficiency, tolerance to multipath fading are the main difficulties in communication system. These complications can be exterminated using Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a parallel transmission scheme, where a high-rate serial data stream is split up into a set of low-rate sub streams, each of which is modulated on a separate subcarrier.

Inventive optical transport networks are often subject to the fixed ITU-T grid and frequency spacing, as well as spectrum over-provision for a low-rate optical channel. For the next generation optical transmission which is evolving to higher data rates, enhancing spectrum utilization is intensively demanded. The pioneering work by Shieh has suggested coherent optical orthogonal frequency division multiplexing (CO-OFDM) to provide spectrum-efficient and elastic long-haul high-speed optical transmissions.

It is also demonstrated that CO-OFDM has high tolerance to optical impairments including chromatic dispersion, polarization mode dispersion and supports higher order modulation techniques. CO-OFDM has been recently proposed in optical transmission since it offers the advantages of high electrical and optical spectral efficiency, dispersion insensitivity, high optical signal-to-noise ratio sensitivity, and computation efficiency.

Each technique has its anomalies, similarly CO-OFDM suffers from frequency offset and phase noise sensitivity, which makes it more sensitive to synchronization errors [1]. Therefore synchronization of CO-OFDM signals deserve careful perusal.[2] Timing synchronization, frequency synchronization and subcarrier recovery are the three steps required in the detection of CO-OFDM. Former two steps are performed in time domain, whereas as the third one is performed in frequency domain.

Generally, timing and frequency estimation techniques are based on exploiting the correlation property of periodical training symbols. One of the popular methods for timing synchronization was proposed by Schmidl and Cox[3] . The timing metric achieved in Schmidl's method has a plateau, which causes a large variance in symbol timing estimation. Minn et al., proposed a modified method with a sharper timing metric to reduce the uncertainty of timing estimation [4], but its estimation variance is still large in the dispersive channels. Finally, Park proposed a modified method with an impulse-like shape at the correct symbol timing point, which further decreases the variance of timing estimation [5]. Nevertheless, Park's method suffers from ambiguity induced by the side lobes of the timing metric and it fails to detect the exact timing point when the training symbol is disturbed by chromatic dispersion (CD) during the transmission. As for frequency synchronization, Schmidl proposed a method employing two training symbols so that the maximum estimation range of the frequency offset can be handled widely [3].

Basically subcarrier recovery includes channel estimation and phase estimation. There are three types of channel estimation, which are as follows: i) Blind ii) Non-blind and iii) Semi-blind. In blind technique transmitted data is not required for channel estimation. It saves the training overhead and is also used for applications where bandwidth is limited. The main drawback in blind technique is it is extremely computationally intensive. Furthermore, non-blind channel estimation is another approach which transmits some portion of the known information to the receiver, which is then used for channel estimation. Non-blind are further divided into two types: i) pilot-aided and ii) preamble. In pilot scheme, which gives better performance in fast fading environment, known information is transmitted together with data. While, in preamble, which is used for slow fading channel, known information is transmitted over one or more OFDM symbols with no data. In semi blind, both known and unknown data is required for channel estimation. Based on LS and MMSE estimators channel can be estimated by using comb type pilot arrangement. MMSE which is complex than LS has been shown to perform much better

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940
International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 4, April 2014

than LS in term of MSE. The interpolation of the channel for comb-type pilot arrangement depends on linear interpolation, second order and spline cubic interpolation .In [12] , Second order interpolation outperforms the linear interpolation and time domain interpolation has low BER as compared to linear interpolation[13].

In this paper, we propose modified timing and frequency synchronization methods with a single training symbol and introduce CD compensation as an aid to increase the performance of the synchronization. The timing synchronization performance, frequency synchronization performance, and bit-error-rate (BER) performance of the proposed method is evaluated on a CO-OFDM system at 20 Gb⁄s by numerical simulations. We are also presenting the DFT-based LS and MMSE channel estimation for CO-OFDM systems, where MSE is improved significantly as compared to conventional LS and MMSE estimators. Section 2 includes timing and frequency offset estimation. Channel estimation is described in section 3.

II. SYNCHRONISATION

A. Timing Offset Estimation

The modified timing method is based on Park's method. By developing the correlation of the conjugate symmetric property of the training symbol, making the timing metric extremely sharp [as shown in Fig. 2],Park progressed further than Schmidl and Minn to enlarge the difference between the correct peak value of the timing metric and others . Training symbol of Park's method is in the form of Spa = [Apa Bpa Apa*Bpa*] (1)

Where Apa represents samples of length N⁄4, Bpa is designed to be symmetric with Apa, and A*pa and B*pa are the conjugates of Apa and Bpa, respectively. This conjugate and symmetric form of the training symbol can be designed by transmitting a pseudo-noise (PN) sequence of "+1" or "−1" on the even frequencies and zero on the odd frequencies.

The impulse shaped side lobes in Park's training metric are responsible for uncertainty of the timing estimation, especially resulting from the k .N/2Lth samples in the cyclic prefix, which is as large as the correct sync flag (k is an positive integer, and L is the number of the identical segments contained in the OFDM symbol).

As our initial aim is to eliminate this uncertainty, we modify Park's timing method by introducing PN sequences of "+1" or "−1" with the same length of the OFDM symbols without the cyclic prefix[7], to be the weighted factors of the training symbol. In order to reduce the side lobes of the timing metric, we multiply the training symbol with the PN sequence weighted factors at the transmitted end. The weighted factors can be removed at the received end only at the correct timing point via the multiplication of the received training symbol and the corresponding PN sequence, which is completely correlated to the weighted factors. We describe the PN sequence as p (k), k = 1,2,…,N − 1,N. Then the form of the modified training symbol is described as

$S_{mod}(k)=S_{pa}(k)*p(k)$,k=1,…,N (2)

The sampled received signal has the following form

$$r(k) = r(k.t_s / N)$$
$$= e^{j(2\pi k f_{off} .t_s/N+\Phi(k))} r_o(k) + N(k) \quad (3)$$

The modified timing metric is given by

$$M_{mod}(d) = \frac{|P_{mod}(d)|^2}{(R_{mod}(d))^2} \quad (4)$$

Where

$$P_{mod}(d) = \sum_{k=0}^{(N/2)-1} \begin{matrix} (r(N/2+d-k).r(N/2+d+k)) \\ .(p(N/2+1-k).p(N/2+1+k)) \end{matrix} \quad (5)$$

And

$$R_{mod}(d) = \sum_{k=1}^{N/2} |r(d+k)|^2 \quad (6)$$

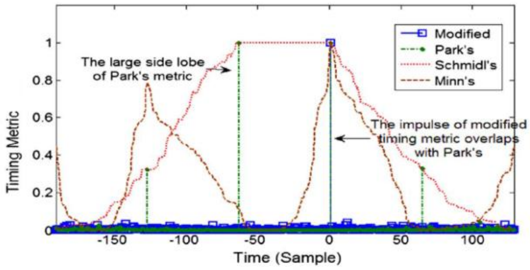

Fig.1:Comparison of different timing metric methods

Each symbol consists of 256 subcarriers and a 64 cyclic prefix, with the symbol period T= 25.6 ns and the guard interval time Tg = 6.4 ns. Gcp is the ratio of cyclic prefix length and the OFDM symbol length, so Gcp = 1/4. The correct timing point is index 0 in the figure. As seen in Fig.2, Schmidl's timing metric makes a plateau for the whole interval of the cyclic prefix, Minn's makes a triangle-shaped timing metric that reduces the plateau, Park's makes an impulse-like timing metric but also has large side lobes, while the modified method eliminates the side lobes in Park's method, further reducing the timing ambiguity.

B. Frequency offset estimation:

After the modified timing synchronization, the correct starting point of the received training symbol can be determined. Then follows the frequency synchronization. The modification of frequency offset estimation is based on Schmidl's method. In the modified method we require only one training symbol consisting of two identical segments. When dt is the right timing point, the modified training symbol with the PN sequence weighted factors removed actually contains two identical segments. Therefore , the modified training symbol cannot only be used for timing but also for frequency offset estimation. The main difference between the two halves of the training symbol will be a phase difference of

IJARCCE

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 4, April 2014

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

$$\Phi = \pi f_{off} / \Delta f \quad (7)$$

where f_{off} is the frequency offset and Δf is the subcarrier spacing Φt can be estimated by

$$\Phi t = angle[P_{freq}(dt)] \quad (8)$$

where

$$P_{freq}(dt) = \sum_{k=0}^{(N/2)-1} r^*(dt+k).r(dt+k+N/2)$$

$$= \sum_{k=0}^{(N/2)-1} |r(dt+k)|^2 e^{j\frac{\pi f_{off}}{\Delta f}} + o(n) \quad (9)$$

dt is the correct timing point. If Φt can be guaranteed to be less than Π, in other words, ft € (-Δ.f ,.Δf), then the frequency offset estimated is

$$ft = \frac{\Phi t . \Delta f}{\pi} \quad (10)$$

As shown in Figure 3 when a CFO of 0.4 is given in the simulated system the estimated value is equal to the actual which shows the minimal MSE using proposed method of frequency synchronization.

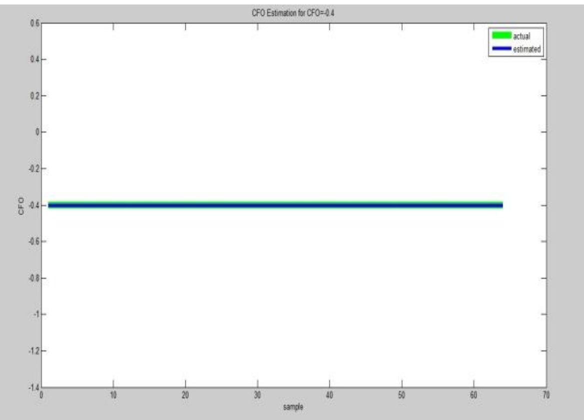

Fig.2:Comparison of actual and estimated CFO

III. CHANNEL ESTIMATION

Training symbols can be used for channel estimation, usually providing a good performance. However, their transmission efficiencies are reduced due to the required overhead of training symbols such as preamble or pilot tones that are transmitted in addition to data symbols.

The least-square (LS) and minimum-mean-square-error (MMSE) techniques are widely used for channel estimation when training symbols are available. We assume that all subcarriers are orthogonal (i.e., ICI-free). Then, the training symbols for N subcarriers can be represented by the following diagonal matrix:

$$X = \begin{pmatrix} X[0] & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & X[N-1] \end{pmatrix}$$

Where X(k) denotes a pilot tone at the kth subcarrier. Note that X is given by a diagonal matrix, since we assume that all subcarriers are orthogonal. Given that the channel gain is H(k) for each subcarrier k, the received training signal Y(k) can be represented as

Y(k)=X(k).H(k)+Z(k)   where Z is the noise

A. LS Estimation

This is the simplest estimator used for channel estimation. In this method without knowledge of channel statistics channel estimation is done. The least-square (LS) channel estimation method finds the channel estimate of H in such a way that the following cost function is minimized:

$$J(Ht)=||Y-XHt||^2$$

$$= (Y - XHt)^H (Y - XHt)$$

$$= Y^H Y - Y^H XHt - Ht^H X^H Y + Ht^H X^H XHt \quad (12)$$

Which gives a solution

$$Ht_{LS} = (X^H X)^{-1} X^H Y = X^{-1} Y \quad (13)$$

LS has low computational complexity as compared to other channel estimators, but its main drawback is high MSE value.

4.2 *MMSE Estimatuion*: MMSE has been shown to perform much better than LS in term of MSE. But MMSE is considered more complex. MMSE has superior performance as compared to the LS
because it utilized second order channel statistics, which minimizes the MSE. The error signal *e* can be written as

e = H- Ht (14)

Where *H* denotes the actual channel estimation and *H and Ht* is raw channel estimation. MSE can be written as

$E\{|e|^2\} = E\{|H – Ht|^2\} = E\{(H – Ht) (H-Ht)^H\}$ (15)

Where *E*{ } is expected value. As the channel and AWGN are not correlated, we can rewrite above equation as

$Ht_{MMSE}= R_{HY} (R_{YY})^{-1}$ (16)

Where *RHH* and *RYY* are the auto-covariance matrixes of *H* and*Y* respectively. While *RHY* is cross-covariance matrix between *H* and *Y*, which can be shown a

$R_{HY} = E \{HY^H\}$
$R_{HY}=R_{HH}.X^H$
$R_{YY} = E\{YY^H\}$
$R_{YY} = XR_{HH}X^H + p.I_N$ (17)

where p is the noise variance

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 4, April 2014

In MMSE estimation, receiver has knowledge of auto covariance matrix R_{HH} .Therefore MMSE can be written as (24)

$$Ht_{MMSE} = R_{HH} X^{H} (X R_{HH} X^{H} + pI_{N})^{-1} . XH_{P,LS}$$

$$Ht_{MMSE} = R_{HH} (R_{HH} + pI (X^{H} X)^{-1})^{-1} . XH_{P,LS} \qquad (18)$$

Final expression for MMSE estimator is shown in equation (24), which requires matrix inversion that has to be calculated each time prior to estimation [13]. Therefore MMSE is considered as a high computational complex estimator.

4.3 *DFT Based Channel Estimation*: The DFT-based channel estimation technique has been derived to improve the performance of LS or MMSE channel estimation by eliminating the effect of noise outside the maximum channel delay. Let Ht (k) denote the estimate of channel gain at the kth subcarrier, obtained by either LS or MMSE channel estimation method. Taking the IDFT of the channel estimate [15]

IDFT{Ht[k]) = h[n] + z[n] n=0,1,……….,N-1 (19)

where z(n) denotes the noise component in the time domain. Ignoring the coefficients that contain the noise only, define the coefficients for the maximum channel delay L as

$ht_{DFT}[n] = h[n]+z[n]$, n= 0,1,2...,L-1 (20)

which is 0 for all other values and transform the remaining L elements back to the frequency domain as follows

$Ht_{DFT}[k] = DFT\{ht_{DFT}(n)\}$ (21)

Fig 4 shows a block diagram of DFT-based channel estimation, given the LS channel estimation. Meanwhile, Fig 5 illustrates the channel estimates obtained by using the various types of channel estimation methods with and without DFT technique discussed in the above. Comparing Fig 6 with Fig 7 reveals that the DFT-based channel estimation method improves the performance of channel estimation.

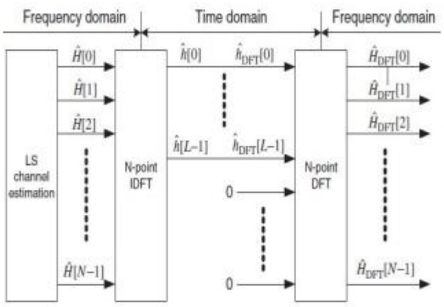

Fig. 3:DFT Estimation Block Diagram

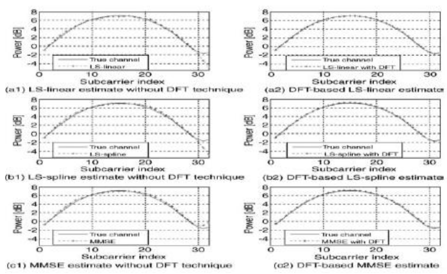

Fig 4

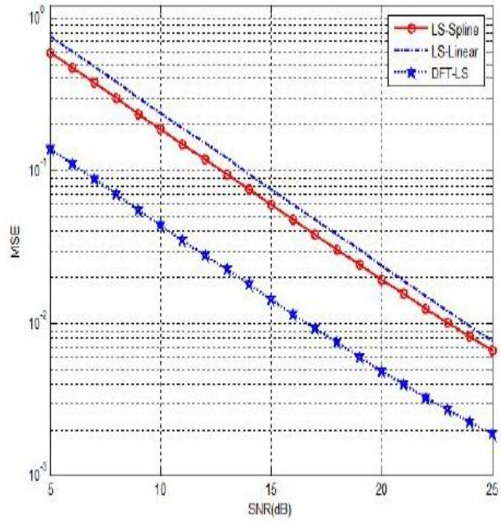

Fig 5

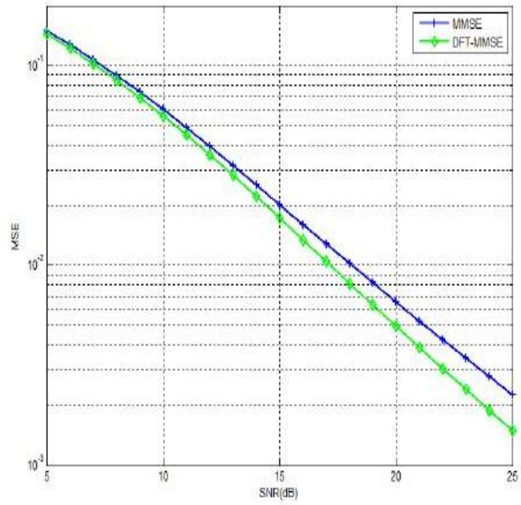

Fig 6

IV. CONCLUSION

In this paper, we modify the timing and frequency estimation methods and implement joint synchronization of timing and frequency with one training symbol. The simulation results verify that the modified synchronization scheme gives a more correct timing estimation than Park's method and other earlier methods and a more economical frequency offset estimation than Schmidl's method, with a wide estimation range and without loss of accuracy in a short transmission distance. Channel estimation based on comb type pilot arrangement is studied through DFT algorithm. The performance of the channel estimators is measured in terms of MSE. The study reveals that the performance of conventional channel estimation techniques (LS and MMSE) can be enhanced with incorporation of DFT algorithm. Improved channel estimation with DFT algorithm has been achieved by removing the impact of noise outside the maximum channel delay length.

REFERENCES

[1] W. Shieh and C. Athaudage , vol. 42,no. 10, pp. 587–589, May 2006, "Coherent optical orthogonal frequency division multiplexing," Electron. Lett.

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 4, April 2014

[2] W. Shieh, 2010, pp. 119–138, OFDM in Optical Communications. Burlington, MA: Academic.
[3] T. M. Schmidl and D. C. Cox, vol. 45, no. 12, pp. 1613–1621, Dec. 1997, “Robust frequency and timing synchronization for OFDM,” IEEE Trans. Commun.
[4] H. Minn, V. K. Bhargava, and K. B. Letaief, vol. 2, no. 4, pp. 822–839, July 2003, “A robust timing and frequency synchronization for OFDM systems,” IEEE Trans. Wireless Commun.
[5] B. Park, H. Cheon, and C. Kang, vol. 7, no. 5, pp. 239–241, May 2003, “A novel timing estimation method for OFDM systems,” IEEE Commun. Lett..
[6] L. Tombal, ., vol. 46, no. 5, pp. 580–583, May 1998, “On the effect of Wiener phase noise in OFDM systems,” IEEE Trans. Commun
[7] G. Ren, Y. Chang, and H. Zhang, vol. 51, no. 1, pp. 139–143, Mar. 2005, “Synchronization method based on a new constant envelop preamble for OFDM systems,” IEEE Trans. Broadcast.,
[8] A. A. S. Quadeer, M. S., 2010, pp. 277-282, "Enhanced channel estimation using Cyclic Prefix in MIMO STBC OFDM sytems," in IEEE International Symposium on Signal Processing and Information Technology (ISSPIT).
[9] Y. Hongwei, vol. 43, pp. 53-60, 2005,"A road to future broadband wireless access: MIMOOFDM- Based air interface," Communications Magazine, IEEE,
[10] M. K. a. A. Ozdemir, H., vol. 9, pp. 18- 48, 2007,"Channel estimation for wireless ofdm systems," Communications Surveys & Tutorials, IEEE.
[11] K. R. K. K.Vidhya , pp. 140-156, 2011,"Enhanced Channel Estimation Technique for MIMO-OFDM System with the Aid of EP Techniques," European Journal of Scientific Research.
[12] H. Meng-Han, Che-Ho and Wei, vol.44, pp. 217-225, 1998, "Channel estimation for OFDM systems based on comb-type pilot arrangement in frequency selective fading channels," Consumer Electronics, IEEE Transactions on.
[13] W. a. Fei, , 2011, "Pilot-Based Channel Estimation in OFDM System," University of Toledo.
[14] L. L. Yi Wang, Ping Zhang and Zemin Liu, vol. 2009, pp. 1-8, 2009, "DFT-based channel estimation with symmetric extension for OFDMA systems," EURASIP J. Wirel. Commun. Netw.,
[15] J. Zhang, Huang and Liqun, 2011, pp. 3929-3932, "An improved DFT-based channel estimation algorithm for MIMO-OFDM systems," in International Conference on Consumer Electronics, Communications and Networks (CECNet).