SFO Estimation Scheme In OFDM-based Power Line Communication System

Yong-An Jung, Young-Hwan You
Computer Engineering
Sejong University
plar@sju.ac.kr, yhyou@sejong.ac.kr
209 Neungdong-ro, Gwangjin-gu, Seoul 05006, Korea

Abstract: - This paper proposes a efficient blind sampling frequency offset (SFO) estimation technique for an orthogonal frequency division multiplexing (OFDM) based power line communication (PLC) system. The main drawback of the conventional estimators is their limited estimation range and their high sensitivity to effect of SFO. To remedy these, this paper proposes two-step correlation scheme that exploits the structure of a transmission data symbol. This paper considers the high–speed ROBO mode of PLC system and focus on OFDM sequences copied by the ROBO interleaver. Computer simulations are employed to assess the performance of the proposed scheme and to make comparison with the conventional scheme.

Key-Words: orthogonal frequency division multiplexing, power line communication, sampling frequency offset, blind estimation.

1 Introduction

Power line communications (PLC) have recently emerged as a highly regarded candidate for in-home, local area and rural broadband multimedia transmissions since power line channels present the appealing benefits of low cost access network installation, due to the use of widely deployed power line infrastructure [1]. Though the high data rates are being achieved using other data networks, PLC network has an added advantage of using the pre-established infrastructure of power lines by which the network coverage can be widely extended to the remote areas. There is a recent research trend to deploy the power lines as a physical communication medium which eliminates the need for a dedicated communication network [2][4].

However, PLC has some drawbacks which must be attended to. Since power lines were not designed for communication, they present negative properties such as attenuation, variable noise, channel transfer functions that vary in time and frequency, and dynamic impedance across the network [5][6]. This harsh environment presents its own set of challenges for communication. Researchers have recently been paying more attention to OFDM as the future PLC transmission scheme, and several techniques to combat PLC noise when using OFDM transmission have been proposed. The OFDM schemes have been successfully implemented to overcome the hardness of PLC channels. The operation of an OFDM system is extremely sensitive to synchronization errors, which may destroy orthogonality among all subcarriers and, thus, cause inter-carrier interference (ICI) and inter-symbol interference (ISI) [7][8]. The synchronization errors may also incur symbol sampling time shift and carrier frequency offset (CFO) in an OFDM receiver. In PLC systems, the most used algorithms for synchronizing OFDM systems explore the repetitive structure of the training symbol (reference block) to find the start point of the OFDM block and estimate the sampling frequency offset (SFO) for continuous and burst operation [9]. However, in time varying channels as the PLC one, a lot of training symbols should be transmitted to maintain synchronization, leading to a decrease of the spectral efficiency. On the other hand, an interesting algorithm not yet explored in PLC applications is the use of redundant information contained within the cyclic prefix to enable the estimation of timing and frequency offset without additional training blocks [10][11]. Considering these problems, this paper proposes a SFO estimation scheme suitable for the OFDM-based PLC system. The proposed synchronization scheme is unaffected by a wide range of SFO. This robust synchronization scheme is totally blind, i.e., it doesn’t require a priori knowledge on the training symbol, nor channel-state information. The proposed scheme performs two-step correlation using the data symbol modulated through the high−speed ROBO mode. The proposed estimator not only can achieve accurate synchronization but also has the advantage of wide acquisition range of SFO.

The rest of the paper is structured as follows. Section II describes the signal model for the OFDM-based PLC system. In Section III, the SFO synchronization estimation method is proposed. Section IV shows simulation results verifying the mean square error (MSE) performances of the proposed scheme. Finally, concluding remarks are discussed in Section V.

2 Signal Model

Consider a discrete-time baseband OFDM system with N subcarrier and N_g guard interval (GI) samples. At the transmitter, N complex symbols are modulated onto N sub-carriers by using the inverse fast Fourier transform (IFFT) on the transmitter side and the last N_g IFFT samples are used to form the GI that is inserted at the beginning of each OFDM symbol. OFDM is very sensitive to the timing and frequency offset, so it is necessary to maintain the synchronization between the transmitter and the receiver. Synchronization can, in general, be achieved by either a pre-FFT approach or a post-FFT. In the pre-FFT synchronization stage, the initial timing and fractional frequency offset estimation are performed based on the GI correlation. Subsequent post-FFT synchronization is based on the pilots being periodic in nature. In this stage, integer frequency offset, CFO, and SFO are estimated. To focus on the estimation of SFO in this paper, we assume perfect symbol timing recovery at the receiver and a rough estimate of frequency offsets is assumed to have been successfully completed at the beginning of the data frame such that only the RCFO is present. For this purpose, we may use the many schemes available in the literature [12][13]. Hence, only small SFO and RCFO will remain during the data section of the frame. A frequency offset will appear as a phase shift $\phi(k)$. Thus, the received OFDM symbol after FFT demodulation is given by

$$R_l(k) = H_l(k)X_l(k)e^{j2\pi\phi(k)(lN_u+N_g)/N}e^{j\pi(N-1)\phi(k)/N} + W_l(k) \quad (1)$$

Where $X_l(k)$ is the transmitted symbol of the k-th subcarrier over the l-th OFDM symbol and $H_l(k)$ is the channel's frequency response with zero-mean and variance σ_H^2. $N_u = N + N_g$, $W_l(k)$ means that inter-carrier interference (ICI) term $I_l(k)$ and zero-mean additive white Gaussian noise $Z_l(k)$ with variance σ_Z^2 during the l-th symbol period. The frequency offset on the subcarrier is comprised of two parts: CFO Δ_f and SFO Δ_s. The former is the same for all subcarriers, while the latter occurs linearly according to the subcarrier index k, i.e., $\phi(k) = \Delta_f + k\Delta_s$. Above, Δ_f and Δ_s represent the normalized CFO and SFO, respectively. This makes the analysis henceforth independent of transmission bandwidth. In the presence of small CFO and SFO, the ICI can be negligible since its power is small with respect to the additive noise $Z_l(k)$ for medium SNR conditions [11]. In this paper, however, its impact on the system performance will be addressed. From [14], we may treat $I_l(k)$ as a zero-mean Gaussian random variable with variance σ_I^2. The magnitude of the phase shift increases linearly with time and must be compensated for to avoid a loss of reference phase in coherent detection.

3 Proposed SFO Estimation Scheme

In this section, we develop a blind SFO estimation algorithm for OFDM-based PLC system. Homeplug Green PHY employs three robust modes of communication, called ROBO modes for several purposes. The ROBO interleavers create redundancy by using the output of the channel interleaver, and reading the output bits multiple times. Each output may occur at a given cyclic shift. This paper considers the two consecutive OFDM symbols in the high−speed ROBO mode of OFDM-based PLC system. Each OFDM symbol contains multiple copies of sequence as follows Figure 1. The presence of $X_l(k)$ and $H_l(k)$ may involve effect hindering the accurate SFO estimation. In order to alleviate this problem, the proposed scheme contains two-step correlation. The first step is to cancel out $X_l(k)$.

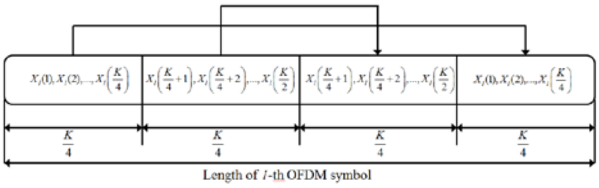

Figure 1: Structure of l-th OFDM symbol for high-speed ROBO mode of PLC system

To cancel out influence of $X_l(k)$, the correlation $\hat{C}_l(k)$ and $\hat{D}_l(k)$ are given by

$$\hat{C}_{l+m}(k) = R^*_{l+m}(k) R_{l+m}(k + \frac{3}{4}K),\ k = 1,2,..,\frac{1}{4}K,\ m{=}0,1 \tag{2}$$

and

$$\hat{D}_{l+m}(k) = R^*_{l+m}(k) R_{l+m}(k + \frac{1}{4}K),\ k = \frac{1}{4}K+1,..,\frac{1}{2}K,\ m{=}0,1 \tag{3}$$

Then, $\hat{C}_l(k)$ and $\hat{D}_l(k)$ are calculated as

$$\hat{C}_{l+m}(k) = H^*_{l+m}(k) H_{l+m}(k + \frac{3}{4}K) \left|X_{l+m}(k)\right|^2 \cdot e^{j2\pi(3K/4)\Delta_s((l+m)N_u+N_g)/N} + \hat{W}_l(k) \tag{4}$$

and

$$\hat{D}_{l+m}(k) = H^*_{l+m}(k) H_{l+m}(k + \frac{1}{4}K) \left|X_{l+m}(k)\right|^2 \cdot e^{j2\pi(K/4)\Delta_s((l+m)N_u+N_g)/N} + \hat{W}_l(k) \tag{5}$$

The second step is used to cancel out $H_l(k)$. The correlation $C(k)$ and $D(k)$ using the two consecutive OFDM symbols are defined by

$$C(k) = \hat{\hat{C}}^*_l(k) C_{l+1}(k),\ \ k = 1,2,..,\frac{1}{4}K \tag{6}$$

and

$$D(k) = \hat{\hat{D}}^*_l(k) D_{l+1}(k),\ \ k = \frac{1}{4}K+1,..,\frac{1}{2}K \tag{7}$$

where we assume that $H_l(k) \approx H_{l+1}(k)$ due to the characteristics of the indoor office environment. Then, $C(k)$ and $D(k)$ can be calculated by

$$C(k) = \left|H_l(k)\right|^2 \left|H_l(k + \frac{3}{4}K)\right|^2 \left|X_l(k)\right|^2 \left|X_{l+1}(k)\right|^2 \cdot e^{j2\pi(3K/4)\Delta_s N_u/N} + \tilde{W}_l(k) \tag{8}$$

and

$$D(k) = \left|H_l(k)\right|^2 \left|H_l(k + \frac{1}{4}k)\right|^2 \left|X_l(k)\right|^2 \left|X_{l+1}(k)\right|^2 \cdot e^{j2\pi(K/4)\Delta_s N_u/N} + \tilde{W}_l(k) \tag{9}$$

The proposed SFO estimator is given by

$$\hat{\Delta}_s = \frac{1}{2}\left\{ \frac{2N}{3\pi K N_u} \arg\left\{ \sum_{k=1}^{K/4} C(k) \right\} + \frac{N}{\pi K N_u} \arg\left\{ \sum_{k=K/4+1}^{K/2} D(k) \right\} \right\} \tag{10}$$

where $\arg\{x\}$ denotes the angle of a complex number x.

4 Simulation Results and discussions

In this section, we evaluate the performance of the proposed algorithm by computer simulations. In our computer simulations, the considered system is compliant with in the 1.8MHz~30MHz frequency band. The FFT size $N = 3072$, cyclic prefix $N_g = 417$, and length of OFDM symbol $K = 916$. class 1 and class 5 of PLC channel model specified in [14] are considered. The performance of the proposed estimator is evaluated in this section by MSE and BER performance.

Figure 2 and Figure 3 show the MSE performance of SFO estimation schemes as a function of the SNR when $\Delta_s = 60\,ppm$. From Figure 2 and 3, one can see that the conventional scheme B has a slightly good MSE performance when SNR $\leq 50\,ppm$. The proposed scheme provides much better results than the conventional methods when SNR $> 50\,ppm$. The proposed scheme is able to effectively mitigate the SFO introduced by small differences in oscillator frequencies.

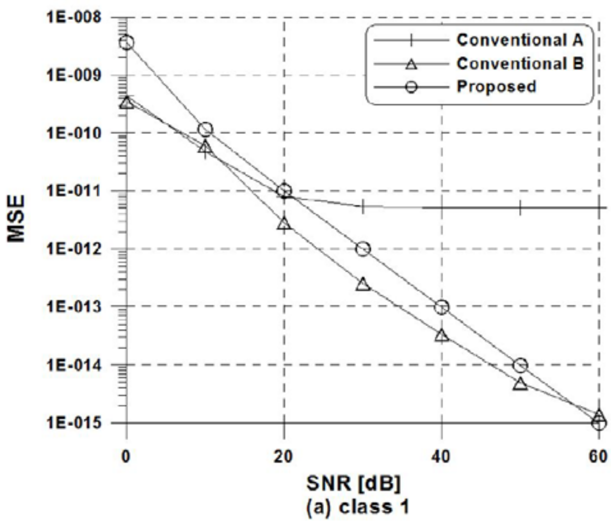

Figure 2: MSE performance of the conventional and proposed SFO estimators versus SNR for class 1

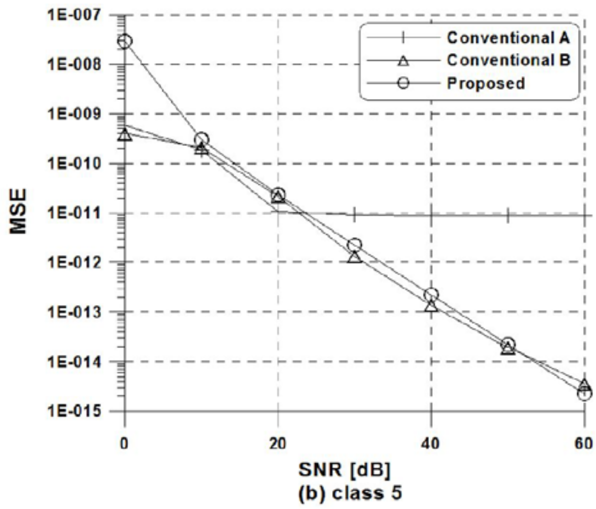

Figure 3: MSE performance of the conventional and proposed SFO estimators versus SNR for class 5

5 Conclusion

In this paper, we propose a blind SFO estimation technique in the OFDM-based PLC system. The proposed scheme considers the high-speed ROBO mode of PLC system and contains two-step correlation. Using the two-step correlation, the influence of channel and transmitted symbol is cancelled out. Simulation results have demonstrated that the conventional SFO estimator is strongly more sensitive to the SFO when compared to the proposed scheme.

Acknowledgement

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2014R1A1A2057122).

References:

[1] H. C. Ferreira, L. Lampe, J. Newbury and T. G. Swart, Power Line Communications: Theory and Applications for Narrowband and Broadband Communications over Power Lines, John Wiley and Sons, 2010.

[2] J. Zyren, "Homeplug Green PHY Overview," Qualcomm White Paper., 2010.

[3] HomePlug Powerline Alliance, "Homeplug Green PHY Specification 1.1.1,", 2013.

[4] N. Taherinejad, R. Rosales, L. Lampe, and S.Mirabbasi, "Channel characterization for power line communication in a hybrid electric vehicle," in Proc. IEEE International Symposium on Power Line Communications and Its Applications (ISPLC), pp. 328-333, March 2012.

[5] N. Taherinejad, R. Rosales, L. Lampe, and S.Mirabbasi, "Channel characterization for power line communication in a hybrid electric vehicle," in Proc. IEEE International Symposium on Power Line Communications and Its Applications (ISPLC), pp. 328-333, March 2012.

[6] O. Amrani and A. Rubin, "Contention detection and resolution for multiple-access powerline communications," IEEE Trans. on Vehicular Technology., vol. 56, no. 6, pp. 38793887, November 2007.

[7] H. Steendam and M. Moeneclaey, "Analysis and optimization of the performance of OFDM on frequency-selective time-selective fading channels," IEEE Trans. Commun., vol. 47, no. 1, pp. 1811-1819, December 1999.

[8] Y. Mostofi and D. C. Cox, "Mathematical analysis of the impact of timing synchronization errors on the performance of an OFDM system," IEEE Trans. Commun., vol. 54, no. 2, pp. 226230, February 2006.

[9] S. Galli, O. Logvinov, "Recent Developments in the Standardization of Power Line Communications within the IEEE," Communications Magazine., vol. 46, no. 7, pp. 64-71, July 2008.

[10] E. Biglieri, "Coding and modulation for a horrible channel," IEEE Communications Magazine.vol. 41, no. 4, pp. 92-98, May 2003.

[11] Dong Liang, Dongwen Niu, BH Zhang, Keyuan Fu, and ZQ Bo, "A design and implementation of timing synchronization algorithm for ofdm-based powerline communication," In 16th IEEE International Symposium on Power Line Communications

and Its Applications (ISPLC)., pp. 212-217, 2012.

[12] H. Zhou and Y.-F. Huang, “A maximum likelihood fine timing estimation for wireless OFDM systems” IEEE Trans. Broadcasting, vol. 55, no. 1, pp. 31-41, March 2009.

[13] Wen-Long Chin, “ML estimation of timing and frequency offsets using distinctive correlation characteristics of OFDM signals over dispersive fading channels,” IEEE Trans. Vehicular Technology, vol. 60, no. 2, pp. 444-456, Feb. 2011.

[14] M. Tonello, S. D’Alessandro, and L. Lampe, “Cyclic prefix design and allocation in bitloaded OFDM over power line communication channels,” IEEE Trans.on Commun., vol. 58, no. 11, pp. 3265-3276, November 2010.