Frame Synchronization Techniques Performance Evaluation in OFDM Based High Voltage Power Line Communication Systems

Navab Ghaedi
Fars Regional Electric Company, Dispatching Group, Shiraz, IRAN
PO box 193,
Tel: +98-711-2142884, E-mail: nghaedi@frec.co.ir

Ramazan Ali Sadeghzadeh
Department of Electrical and Computer Engineering, K.N. Toosi University of Technology, Tehran, IRAN
E-mail: sadeghz@eetd.kntu.ac.ir

Abstract

In this paper two of OFDM frame synchronization algorithms in High Voltage PLC (HV PLC) system has been studied under the same overall working conditions (i.e., transmitted power and global data rate). By using preamble at first method, there is a compromise between SNR and transmission bandwidth. However, in cyclic prefix (cp) at first method, we can attain a higher data rates for a given bandwidth. Comparisons show that by using least square (LS) channel estimation and comb type pilot frame format, preamble at first method outperforms cp at first method, under the same conditions at lower SNRs.

Keywords: PLC (Power Line Carrier) system, OFDM (Orthogonal Frequency Division Multiplexing), sycnchronization, preamble, Impulsive Noise, Corona Noise, Least Square (LS) channel estimation.

1. Introduction

There are increasing trends to exploit existing powerline systems to transmit data. Data transmission over power lines has been implemented in the past at very low data rates for applications such as automation and metering. Data transfer rates in such systems range from 3 KHz to approximately 500 KHz (a few Kbps). The realization of broadband communications services over power line grids offers a great opportunity for cost-effective telecommunications networks without the laying of new cables. On the other hand, electrical supply networks are not designed for communication which can not guaranty the performance from the view point of signal transmission and there are some limiting factors in the application of broadband PLC technology. Therefore, coverable distances, realizable data rates as well as transmitted signal power (due to Electromagnetic Compatibility (EMC)) are limited in PLC systems. For the realization of broadband PLC, a significantly wider frequency spectrum is needed (up to 30 MHz) than is provided within CENELEC bands. So, broadband PLC systems have to cope with a limited signal power, which decreases their performance (data rates, distances) (Atefat Doost, et al., 2011). Furthermore, high attenuation at high frequencies, impulsive, corona and narrowband noise as well as multipath are some of the distortion effects that are present in such systems. Therefore, power lines provide a challenging medium for transmission of high data rate information.

In OFDM, frame synchronization is an essential requirement, because OFDM signals are transmitted block by block and there is a carrier and sampling frequency offsets. Concerning symbol synchronization, constraints are less tough. Synchronization problems have received a lot of attentions (Minn, et al., 2003; Wen, et al., 2008; BAE, J.; Kim, E. 2010; Deinzer, 1999). Some of them are data aided, which use pilot or training sequences, while others are not data aided. In the OFDM systems, both data aided and non-data-aided synchronization algorithms have been proposed previously (Minn, et al., 2003; Wen, et al., 2008; BAE, 2010; Deinzer, 1999). Within the non-data-aided algorithms, the cyclic property of the guard interval could be employed for the symbol synchronization without any training symbol in the OFDM systems. Among those non-data-aided algorithms, the estimator exploits the second-order cyclostationarity of the received signals and, then, it obtains the information of symbol-timing offset by the cyclic correlation. Within the data-aided algorithms, at the receiver, the symbol synchronization could be implemented with the aid of the dedicated training symbols or pilot symbols. The frame synchronization using the designed training symbol has been usedsed.

So far, some researches dedicated to synchroniaztion and channel estimation methods performances in OFDM based low voltage power line carrier systems (Atefat Doost, et al., 2011; BAE, 2010; Deinzer, 1999 and their references). In this article, two of main preamble aided synchroniaztion method in HV digital PLC systems simulation by using OFDM technique with comb type pilot frame format as well as LS channel estimation based on linear interpolation technique is considered.

This paper is organized in the following manner. Section 2 contains simulated system overview, while section 3 gives simulation results. Conclusions are located at the end.

2. Simulated System Model

The OFDM overall system model is shown in Fig. 1. Transmitter, PLC channel, and receiver are modeled as in (Atefat Doost, et al., 2011).

Comb type pilot frame format is commonly used in many communication system standards such as IEEE802.11 WLAN. Similar to PLC system simulations presented in (Aghajeri, et al., (2002); Estopi˜n´an, et al., (2004)), comb type pilot frame format based on the IEEE802.11 standard data frame format is used in this work. In these simulations, it is supposed that there are 48 data and four pilot subcarriers in every OFDM frame. Pilot symbols are inserted in 1, 16, 31 and 46 subcarrier positions of each frame. These pilot symbols will be used during channel estimation operation at the receiver side. OFDM signal without cyclic prefix is as:

$$s(n) = s(nT) = \sum_{k=0}^{N-1} S(k)\exp(j\frac{2\pi kn}{N}) \qquad 0 \le \mathrm{n} \le \mathrm{N-1} \tag{1}$$

for which $S(k)=a_k+j.b_k$ is k-th M-PSK or M-QAM symbol and N is the number of subcarriers. Throughout this paper, a QAM modulation is used.

In order to reduce inter symbol interface (ISI) and inter carrier interface (ICI), as much as possible, a guard time distance (cyclic prefix) of length N_g is inserted at the beginning of every OFDM symbol and is removed at the receiver side before FFT operation. Synchronization preamble sequence (Walsh code with length of N_c) are added at the beginning of the frame (Fig. 2) and is removed at the receiver side before FFT operation. This synchronization sequence is detected by a matched filter correlator in the receiver side to find the beginning of the data frame.

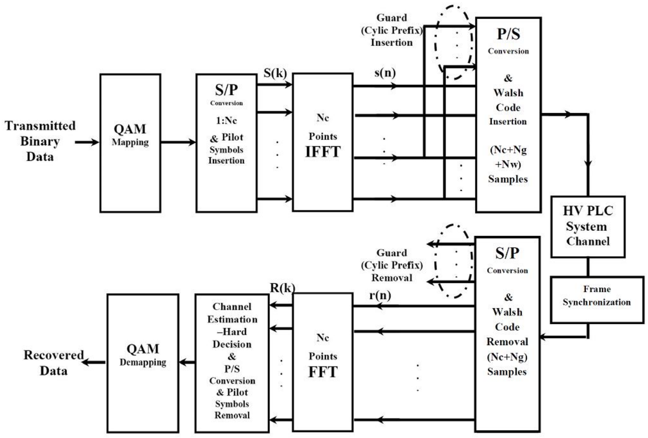

Figure 1. Transmitter, PLC channel and receiver block diagram in baseband OFDM system

Walsh Code	Cyclic Prefix	OFDM Signal: s(n)

Preamble at first method

Cyclic Prefix	Walsh Code	OFDM Signal: s(n)

Cyclic Prefix at first method

Figure 2. Synchronization frame formats: Preamble (Walsh code) at first method and CP at first method

By these operations symbol duration is extended to $N1 = N_c+N_g+N$. A guard interval longer than the powerline channel impulse response of some microseconds ($N_g>=N_{max}+1$, for which N_{max} is the maximum channel delay) increases robustness against multi-path signal propagation at the expense of slightly reduced bandwidth efficiency.

HV-PLC channel model consists of L-ptah multipath transfer function and Corona and Impulsive noises. These two characteristics models are simulated as in (Atefat Doost, et al., 2011).

The received signal at receiver side would be as below:

$$\underline{r}(n) = \sum_{l=1}^{L} \alpha_l(n) \cdot \underline{s}(n-\tau_l) + \underline{n_{corona}}(n) + \underline{n_{impulsive}}(n) \tag{2}$$

for which $\alpha_l(n)$ is channel fading coefficient of l-th channel, $s(n)$ is transmitted baseband signal, r(n) received baseband signal, and $n_{corona}(n)$ and $n_{impulsive}(n)$ are corona and impulsive noises respectively. The power of corona and impulsive noises are $\sigma_{corona}^2 = \sigma^2/(1+ICR*pi)$ and $\sigma_{impulsive}^2 = ICR* \sigma_{corona}^2$, for which σ^2 is the power of the overall noise, which includes corona and impulsive noises, pi is probability of impulsive noise occurrence and ICR is impulsive to corona noise power ratio. In our simulations ICR=100 and pi =0.01 are used. If transmitted frame symbols are transmitted sequentially, only one block frame Walsh (preamble) code could be used.

Before demodulating the received signal in OFDM system, the receiver has to do frame synchronization, frequency synchronization and channel estimation. In this study, the carrier frequency synchronization is not considered. The receiver should remove the cyclic prefix and Walsh code, the synchronization should be done. Once, timing information provided by the synchronization algorithm, one could exactly remove the prefix and, then, use FFT to extract the transmitted data. Matched filter correlator based frame synchronization is done as in (Wen, et al., 2008 and Jafari Sadeghi, et al., 2012) and the first frame start point is found.

As seen in Fig. 1, after removing Walsh code and cyclic prefix and doing N points FFT operation, the received signal will be as (if there is no ISI):

$$\begin{aligned} &R(k) = FFT\{r(n)\} = S(k).H(k) + \\ &+ N_{corona}(k) + N_{impulsive}(k), \qquad 0 \le k \le N_c - 1 \end{aligned} \tag{3}$$

The impulsive noise is spread over N data symbols due to the FFT operation, which is different in the single carrier system, in which the impulsive noise will affect only one symbol (Atefat Doost, et al., 2011). Hence the total noise is $N=N_{corona}+pi.N_{impulsive}$, where N is the PSD of the overall noise and pi is the average impulsive noise rate.

In comb-type pilot based channel estimation, N_p pilot signals (symbols in OFDM) are uniformly inserted into N_d data subcarriers S(k) in the frequency domain according to the following equation (Coleri, et al., 2002):

$$\begin{aligned} S(k) &= S(mL + l) \\ &= \begin{cases} S_p(m), & l = 0 \\ \inf.data & l = 1,\ldots,L\text{-}1 \end{cases} \end{aligned} \tag{4}$$

where L=total number of subcarriers/N_p and $S_p(k)$ is the m-th pilot carrier value. By defining $\{H_p(k), k=1, 2, \ldots, N_p\}$ as the frequency response of the channel at the pilot sub-carriers. Assuming perfect timing synchronization, channel estimation over pilot parts based on LS estimation is given by $\hat{H}_p(k) = R_p(k)/S_p(k)$, (k=1,…,$N_p$), where $S_p(k)$ and $R_p(k)$ are k-th transmitted and received pilot sub-carriers respectively. So channel estimates at data positions can be calculated by using appropriate interpolation method between two consecutive channel estimates of pilot parts ($\hat{H}_p(k), \quad \hat{H}_p(k+L)$).

In comb-type pilot based channel estimation, an efficient interpolation technique is necessary in order to estimate channel at data -subcarriers by using the channel information at pilot subcarriers.

In the linear interpolation method, the channel estimation at data carrier k, $mL < k < (m+1)L$ (where L= total number of subcarriers/N_p), using linear interpolation is given by (Coleri, et al., 2002):

$$\begin{aligned} \hat{H}(k) &= \hat{H}(mL + 1) \qquad 0 \le 1 \le \text{L} \\ &= (\hat{\text{H}}_\text{p}(m+1) - \hat{H}_p(m))\frac{1}{L} + \hat{H}_p(m) \end{aligned} \tag{5}$$

The second-order, third-order and lowpass interpolation available in the simulation software (interp function in MATLAB) produces a smooth and continuous polynomial fitted to given data points.

Afterward, channel estimations for data subcarriers are calculated from $\hat{S}(k) = R(K)/\hat{H}(K)$ (where k=1, 2, …, N_d) and finally, by applying hard-decision and demodulation, data bits are obtained. Since the OFDM link can be synchronized, ISI and ICI can be avoided by choosing an appropriate guard interval (Atefat Doost, et al., 2011).

3. Simulation Results

In contrast to our previous work (Atefat Doost, et al., 2011), frame synchronization is examined by using missing probability of frame start and bit-error-rate (BER) simulation criteria with about 10^5 bits in HV PLC channel as in Monte Carlo method. Simulation parameters are as in table 1. Total 10^5 data bits are simulated and BER is gained from comparing the hard-decision demodulated symbols with the true symbol constellations.

Simulation results are shown in figures 3 and 4. In Fig. 3 the performance is evaluated based on the missing probability of frame start (MPFS) for ideal (perfect) channel estimation and frame synchronization based on LS criterion and preamble (Walsh code) at first and CP at first methods.

Table 1. Simulation parameters

Parameters	Value	
Bandwidth	500 KHz	
Distance (space) between Subcarriers (Δf)	6.25 KHz	
T_{fft}	64	160 µs
Cyclic prefix	4	10 µs
Symbol Length	68	170 µs
Number of data Subcarriers	48	
Number of pilot subcarriers	4	
Total Number of subcarriers	64	
Length of Walsh code (N_c)	8	
Modulation	QAM	
Data Rate	1 Mbps	

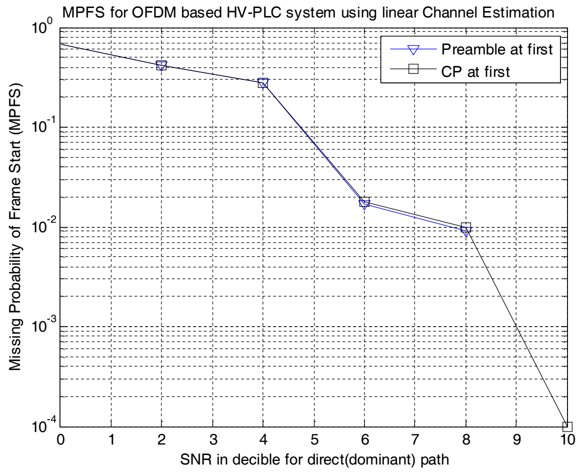

Figure 3. Missing probability of frame start by using ideal (perfect) channel estimation

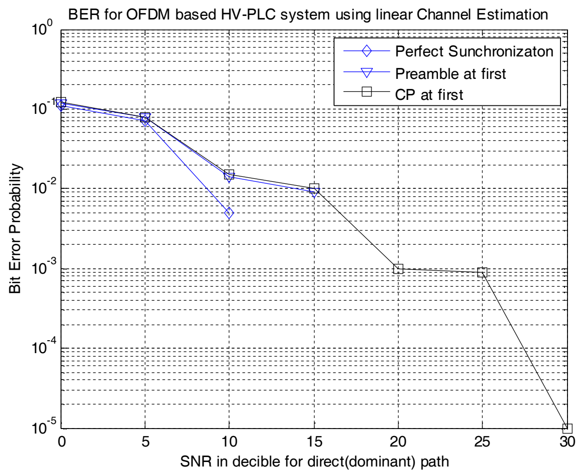

Figure 4. BER by using LS channel estimator with linear interpolation

From this figures, it can be seen that, in both of synchronization frame formats, by increasing the SNR, the MPFS and BER is decreased. However in synchronization frame format of preamble (Walsh code) at first, offers at least approximately 2 dB gain over the CP at first scheme at a MPFS of 0 at SNR of 10 dB and 5 dB gain in BER of 10^{-4} at SNR of 25dB.

4. Conclusions

In this paper the immunity of OFDM technique in high voltage PLC to frequency selective fading channel, corona noise and impulsive noise are examined.

Reliable frame synchronization could be obtained under a low signal-to-noise (SNR) environment. Based on the pseudo-noise (Walsh) sequence preambles, OFDM synchronization gives a better detection in terms of the low false error and low missing error. Based on the constant envelope preamble, the synchronization algorithm exploits the correlation property of the PN sequence and the two identical parts of the preamble to estimate the timing offset (Tlili, et al., 2003).

Simulation results for PLC channels show that when pilot symbols with comb type frame format (with symbol base channel estimation in OFDM are applied with 1st order interpolation, an appropriate performance is attained. Synchronization frame format of preamble (Walsh code) at first outperforms CP at first method, because of HV PLC channel transfer function linear behavior during each subcarrier and slow amplitude and also phase variations between two consecutive pilot symbols (at null or data subcarriers). This method could enhance overall channel estimation system performance. On the other hand, using this frame synchronization method and one tap in OFDM technique allows to reduce channel equalizer complexity and to increase tolerance to narrowband and impulsive noise. By comprehensive studies over synchronization techniques, we can have a more clear view on selecting the best technique among different schemes.

References

Atefat Doost, E. , Ghamat, M. H., Ghaedi, N., Golabi M., (2011), Evaluation of Adaptive Modulation Technique in PAPR Reduction in OFDM Based High Voltage Power Line Communication Systems, 13th IEEE International Conference on Advanced Communication Technology 2011 (ICACT2011), South Korea, 2011.

Minn, H., Vijay K. Bhargava, Khaled Ben Letaief, (2003), A Robust Timing and Frequency Synchronization for OFDM Systems, IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 2, NO. 4, pp. 822-839, JULY 2003.

Wen, Jyh-Horng, Gwo-Ruey Lee, Jia-Wei Liu, Te-Lung Kung, (2008), Frame synchronization, channel estimation scheme and signal compensation using regression method in OFDM systems, Elsevier, Computer Communications 31, pp. 2124–2130.

BAE, J.; Kim, E. (2010), Novel OFDM frame synchronization scheme based on repeated orthogonal gold sequence for power line communication systems, Fourth Workshop on PLC, Germany, September 2010, pp. 13-16.

Deinzer, M. and Stoger, M. (1999), Integrated PLC-modem based on OFDM, 3rd Inter- national Symposium on Power-Line Communications, (Lancaster, UK), pp. 92-97, (Apr. 1999).

Aghajeri, S., Shafiee, H.R., Mohammadpour-Velni, J., (2002), Design of an OFDM System for High Rate Communication over Low Voltage Power Lines, Proceedings of MED2002 Lisbon, Portugal, (July 2002).

Estopi˜n´an, P., Purroy, A., Sanz, A., and Garc´ıa, J. I. (2004), Broadband PLC Communication System in C Band, IEEE Conference, ISPLC2004, 2004, pp. 369-373.

Jafari Sadeghi, S. M., Derakhtian, M., Masnadi-Shirazi, M. A., (2012), Design and Implementation of an OFDM-based Voice Transmission System for Mobile Underwater Vehicles, IEEE, ISCC 2012, pp. 49-52.

Tlili, F., Rouissi, F., Ghazel, A., (2003), PRECODED OFDM FOR POWER LINE BROADBAND COMMUNICATION", IEEE, 2003, pp. 109-112.

Coleri, S., Ergen, M., Puri, A., Bahai, A., (2002), Channel Estimation Techniques Based on Pilot Arrangements in OFDM Systems, IEEE Trans. On Broadcasting, Vol. 48, No. 3, pp. 223-229, (September 2002).