JOINT ESTIMATION OF CHANNEL AND IMPULSE NOISE IN AN OFDM BASED SYSTEM FOR A POWERLINE NETWORK USING ADAPTIVE GUARD LENGTH

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Abstract

This paper considers OFDM based joint estimation of channel and impulse noise with an adaptive guard length for a powerline channel. The purpose of adaptive guard length is to cater for the channel variations caused due to time varying behavior of powerline network. Results show that the utilization of joint channel and impulse noise estimation gives improved bit error rate performance as well as efficient utilization of available bandwidth. Also the simulation results confirm that performance of proposed adaptive guard band method with joint estimation is better as compared to the fixed guard length for the communication system.

Keywords: Powerline channel, Guard band, channel estimation, impulse noise, channel impulse response

Introduction

Pilot based channel estimation plays a vital role in the overall system performance improvement in communication regime. The situation becomes more challenging in the presence of impulsive noise in both wireless and wired communication systems, where the occurrence time of impulse noise (IN) cannot be predicted beforehand. If not dealt with, this unpredictable timing along with high power of IN can degrade the system performance severely. In case of wired communication, powerlines are gaining attention day by day as a cheaper communication medium.

The global standards including IEEE 1901, HomePlug etc. have defined a powerline communication (PLC) channel to be capable of accommodating broadband communication. But powerlines exhibit above defined harsh and unpredictable behavior for communication signal propagation, as their primary usage was intended for power transmission only (J Lin, Brian, L Evans 2013). As a result the usable channel bandwidth drops more beneath the theoretically defined limits. Hence it is important to devise mechanisms of pilot based estimation which are bandwidth efficient to deal with this problem and to make PLC channel an appropriate candidate for broadband applications. One solution can be the utilization of compressed sensing algorithm using joint pilot set instead of separate ones for both channel and IN estimation (H. Gacanin 2013). This will result in reduced pilot overhead, thus making the system bandwidth efficient. In (A. Mehboob et al 2013) a joint scheme for both channel and IN estimation has been suggested but no attention is paid to the varying channel impulse response (CIR) length.

In order to capture the accurate picture of a varying PLC channel contaminated with IN, it is important to cater for the channel and IN estimation along with adaptive adjustment of windowing function to the varying CIR length. It is seen that the load conditions in a powerline network keep varying, due to the devices switching on and off, which results into change in multipath behavior causing different number of delayed copies of transmitted signal arriving at the receiver every time. If not taken care of, these delayed signal copies interfere with the next symbol resulting into inter symbol interference (ISI) causing an increase in bit error rate (BER).

In recent past, orthogonal frequency division multiplexing (OFDM) scheme has been utilized to cope with this multipath interference. It provides better shielding against ISI and results into improved BER. To avoid the delayed copies of previous symbol interfering with the next one, OFDM provides the user with a guard band in the form of a cyclic prefix. The presence of GI makes OFDM a good choice for PLC channel but keeping in mind the varying channel conditions, fixing guard interval (GI) at a single value may compromise the overall system performance (H. Gacanin, F. Adachi 2009). In case the number of multipath gets larger than the fixed GI length the result would be performance degradation of the equalizer due to increased ISI. Conversely, if the CIR length is decreasing in comparison with the predefined guard band, the useful system bandwidth will be wasted in extra length of fixed guard band. These changes in channel are reflected upon the CIR length (effective CIR length may decrease or increase).

The purpose of this research is to device a mechanism that can jointly estimate the channel and IN and also adjusts the GI length according to the varying channel conditions mentioned above. The rest of the paper is arranged as follows; section 2 expresses the system model being analyzed, section 3 provides simulation results and section 4 concludes the paper.

Compressed Sensing Based Channel Estimation

This section provides readers a brief overview of CS estimation. We utilize the least absolute shrinkage and selection operator (LASSO) algorithm from RIPLess theory of CS. Its mathematical expression is given,

$$min_{x\in C^N} \frac{1}{2}\{\|A * \emptyset_i - y\|_2^2 + \lambda|\emptyset_i|_1\},$$

The approach used by CS is different in that the received signal is not sampled at all the locations, instead, only J<<N noisy measurements are taken from the dictionary matrix [11], [12]. Here J×N sensing matrix is built from the dictionary to ease the reconstruction of signal at the receiver side. It is worth noticing that the signal is reconstructed from the dictionary along with the received pilot symbols information carried in Y(t). Mathematically CS problem can be given as,

$$Y(t) \ = \ x * \emptyset \ + \ n_0(t)$$

Here $\emptyset$ is the sensing matrix and 'x' is being observed by the sensing matrix (this observation is taken in the form of inner product between sensing matrix and the channel coefficients matrix). After finding 'x' it is easy to reconstruct x from the received signal Y(t). Here 'x' will be computed by using the LASSO algorithm.

System Model

We assume an OFDM based communication system where each subcarrier in OFDM is further binary phase shift keying (BPSK) modulated, with no interference of CIR and IN supports and an increasing CIR length (H. Gacanin 2013), (A. Mehboob et al 2013). Also transmitter and receiver are assumed to be perfectly synchronized. Figure 1 represents the diagram of the system utilized in this work. Let N be the total number of subcarriers and J be the number of pilot subcarriers. So, in each OFDM frame there would be N-J data symbols. The pilot positions are uniformly allocated. An initial GI length is appended and is denoted by L_G, the symbol duration is represented by T_{sym} and the OFDM symbol is modulated. The resultant signal x is transmitted over the PLC channel, with channel impulse response h.

The received signal Y can be represented mathematically as,

$$y = \ x * h + \ n_{\mathrm{k}}$$

Frequency domain equivalent of the received signal can be given as,

$$y_k = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \left(\frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} (s_k H_k) e^{\frac{j2\pi kn}{N}} \right) e^{\frac{-j2\pi kn}{N}} + N_k$$

where k and n vary from 0,1,2,…,N-1 and $\mathrm{s_k}, \mathrm{H_k}$ represent the kth symbol in OFDM frame and the channel frequency response at kth index respectively. '$\mathrm{N_k}$' is the kth noise component in the received OFDM frame. The noise $\mathrm{N_k}$ in frequency domain is

$$N_k = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} N_i e^{\frac{-j2\pi in}{N}} \text{ with } i=0,1,\ldots N\text{-}1,$$

The time domain equivalence of this noise is assumed to be composed of two components, Gaussian component and IN,

$$n_i = n_g + n_{IN}$$

We utilize a multipath channel with P paths, where P may vary from 5-20 taps in a typical PLC channel.

Next step is to perform channel and IN estimation to obtain the transmitted signal 'x' free of IN and other channel impairments. This requires the estimation of both PLC channel

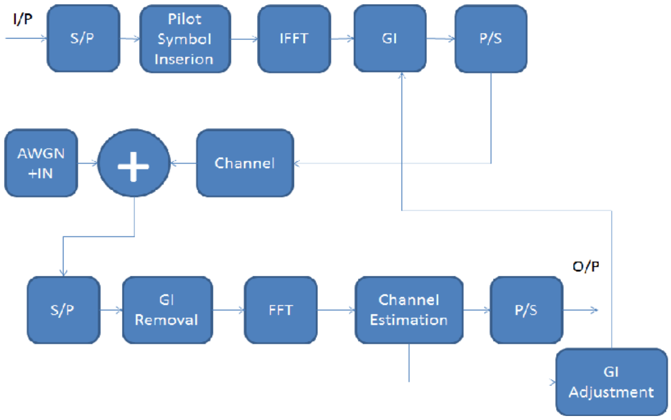

Figure 1. Block diagram showing the OFDM based communication system utilized.

and IN to counteract the effects of both from the received signal 'y' and to recover the signal correctly [3]. The received signal sampled at pilot indices J is mathematically expressed as,

$$Y_J = X_J H_J + N_{g,J} + N_{IN,J}$$

Where $N_{g,J}$ and $N_{IN,J}$ is sampling of AWGN and IN at pilot locations,

Let,

$$N_{t,J} = N_{IN,J} + N_{g,J},$$

$$Y_J = X_J H_J + N_{t,J}$$

As discussed already, we will consider the joint estimation of channel and IN to lower the number of pilot tones than those required by the separate schemes for channel and IN estimation. The assumption is made that due to non-zero pilot symbols, the values of channel and IN would be superimposed upon each other at the pilot indices. But the IN and channel support set are not supposed to interfere. Authors in (A. Mehboob et al 2013) state that the probability of IN occurrence in the first r samples q=0,1,..5 against the overall IN occurrence in OFDM frame is as low as 0.01, hence it is safe to recover the channel estimates from the first r samples of Y_J only without interference with IN samples. Figure1 shows the probability function of the occurrence of q=0,1,..5, impulses in first r samples.

Joint Estimation of Channel and IN

We have utilized here a joint set of non-zero pilot symbols for estimation of both channel and IN.

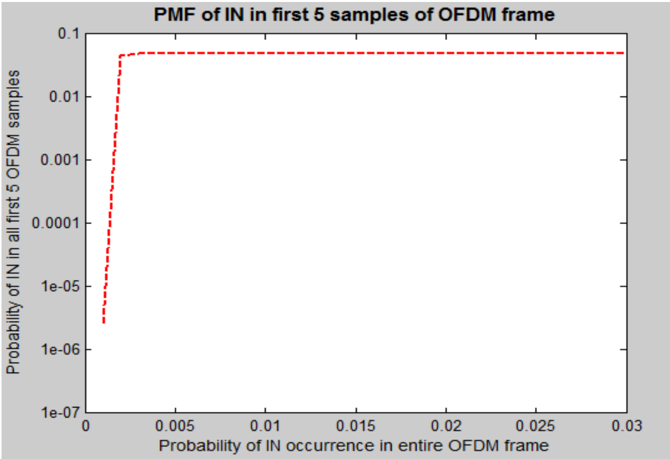

Figure 2. Probability distribution of IN supports interfering with CIR.

The CS estimate of the intermediate signal can be given as;

$$\hat{h}_{Cs}(t) = (X^H * X)^{-1} X^H * Y = X^{-1} * Y$$

Having obtained the intermediate joint estimate we can get the channel estimate h(t) by taking the first K samples only i.e.

$$h_t = \begin{cases} h_{Cs}(i), & i = 0,1,..K-1 \\ 0, & otherwise \end{cases}$$

h_t can now be interpolated using FFT and then IFFT operation can be performed to get CIR. The IN estimation can be performed upon the remaining $\hat{h}_{Cs}(t)$ as follows;

$$n_t = \begin{cases} 0, i = 0,1, \dots P-1 \\ h_{Cs}(i), i = P,..N-1 \end{cases}$$

Since IN is additive in nature, this estimated IN response is to be subtracted from the received signal. The channel equalization is performed in the next step to mitigate the channel effects from the received signal.

The joint estimation provides improvement in the performance of channel estimates. To fully capture the varying nature of a powerline channel and to further optimize the system’s bandwidth efficiency, length of guard band needs to be adjusted according to the varying CIR length. This technique is discussed next.

GI Length Adjustment Method

We consider the decrease in effective CIR length as compared to the pre-defined GI length. Purpose of this GI length adjustment is to save the excess bandwidth that is being wasted in appending greater length of GI interval than actually required. GI length adjustment method will take the initial channel estimates using the LASSO estimation discussed earlier. Let h(t) be the required initial channel estimate. We run the procedure for V=0,1,.. L_G-1, thus performing the windowing of the CIR. After performing the windowing $h_i(t)$ is obtained, whose FFT can be taken to obtain improved frequency response $H_I(K)$. Next, for every iteration of search method, we calculate the MSE on that index K using the formula;

$$MSE(V) = \sum_{r=0}^{N-1} |H_I(K) - H_c(K)|^2,$$

where H_I is improved frequency domain channel response and H_c is the initial channel estimate in frequency domain. The cost function to be computed here is the ratio of mean error of present value to the previous one.

$$C(K) = \left| \frac{MSE(K+1)}{MSE(K)} \right|$$

Next we estimate the K index that will maximize the cost function C(K). As maximum C(K) value denotes the maximum distance between initial channel estimates H_I and the improved ones, which in turn points to the number of samples by which the CIR needs to be adjusted. The output of the search method is the number of samples 'alpha' by which we need to estimate the optimized frequency response $H^\alpha(K)$. Finally that value of alpha is assigned to L_G. This new value of GI length is next time utilized for transmitting the OFDM frame. Every time the GI length is required to be appended, this method will be called except for the first iteration which will be using the initial value of GI length.

Simulation Results

An OFDM based communication system is utilized with N=256, J=32, P=5, L_G=16 and p=0.01. Whereas for separate estimation, we take J_I=12 and J_C=20 tones for IN and channel estimation respectively. We compare the performances of both separate and joint CS based schemes in terms of bit error rate for CIR and IN estimation using LASSO algorithm. It can be seen in figure 2 that the proposed joint scheme gives 4 dBs gain in achieved BER over the separate estimation scheme. The reason is that the increase in number of pilot tones in case of joint estimation increases the estimation accuracy of IN and as a result the BER improves. It is also evident from the results that the joint estimation scheme gives better results although the number of pilot overhead is small, which means that joint estimation scheme is bandwidth efficient.

Next we investigate the impact of GI length adaptability, figure 3 shows that at lower Eb/No values the increase in value of alpha does not affect the cost function very much which stays under 10 dBs. But as Eb/No increases, the cost function also gives better resolution in terms of defining the difference between previous and present value of channel frequency response. Also it is evident from figure 3 that at each Eb/No level, the cost function stays at the same level till the value of alpha is equal to P. This proves the dependence of cost function on the number of channel reflections and their effect upon channel frequency response.

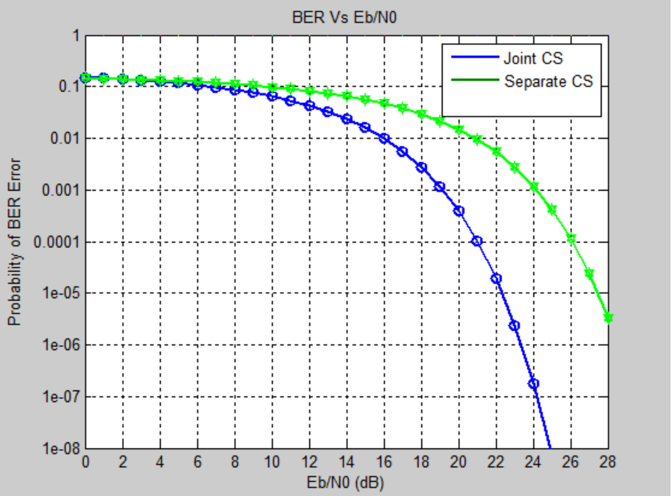

Figure 3. BER comparison of separate and joint CS based estimation schemes.

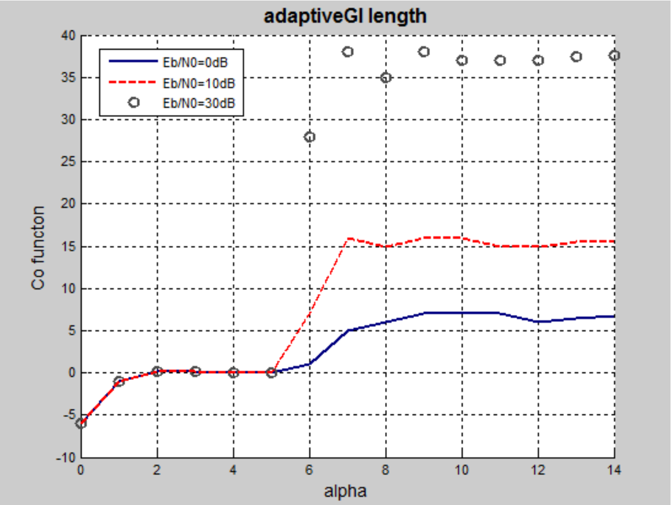

Figure 4. performance evaluation of GI length adjustment for different Eb/No levels.

Conclusion

In this research, we have proposed a joint channel and IN estimation scheme along with adaptive GI length. It is shown that the said technique performs better in a time varying PLC channel, by giving almost same BER as the separate channel and IN estimation scheme and at the same time it cuts down the number of pilot overhead, thus providing a bandwidth efficient estimation scheme. The adaptive GI length further allows the system to utilize the available bandwidth more efficiently, by reducing or increasing the GI length according to the changes in channel conditions. The results show performance improvement of the proposed technique over the separate estimation technique without GI length adjustment, in the form of improved BER rate.

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