Channel Estimation Based on Frame Control symbol Re-encoding and Re-Mapping in IEEE Std. 1901-2010

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Abstract

The present work focuses on channel estimation in power line communications, by re-encoding and re-mapping the Frame Control (FC) symbol. The main contribution of this work is to show that it is not necessary to carry out a second estimation of the channel frequency response (CFR) but only update the noise power spectral density (NPSD) for obtaining remarkable improvements in a power line communications (PLC) system. This conclusion makes feasible its implementation in practical systems because our proposal does not lead to delays, nor additional computational costs. The gain obtained by this update is substantial and the system behavior, especially in presence of narrow-band (NB) noises, improves considerably. A PLC system according to the specifications of IEEE Std. 1901-2010, was used to evaluate our proposal. Results have been tested on a multipath channel and narrow-band noises.

Index Terms

Channel estimation, frame control symbol re-encoding, narrow-band noise, IEEE Std. 1901-2010.

I. INTRODUCTION

THE use of power distribution networks for data communications systems is at the same time the main advantage and Achilles' heel of power line communications. As transmission occurs on a wiring network not designed for high-speed communications, PLC suffers from one of the most aggressive communication channels. The diversity and relatively high power level of noise, as well as strong fading caused by the multipath effect, are still a challenge regarding the development of this technology.

Channel and noise estimation are critical processes that must be performed at the receiver in order to ensure robust demodulation in this harsh channel. There are several approaches to estimate the PLC channel. Based on knowledge of a preamble sequence, the linear minimum mean-squared error (LMMSE) estimator has been one of the most extensively used [1]–[3]. Many contributions focus on modifying the CFR estimation methods [2], [4], or on interpolation methods [5] used to extrapolate from a sparse observation (with a reduced number of subcarriers) to be compliant with the IEEE Standard 1901-2010 [6]. However, it has been proved that increasing the interpolation order, or using more complex kernels will not carry high gains to the system [7].

Another option is to use the frame control (FC) symbol to refine the channel estimation [6], [8]. Exploiting that FC symbol must be perfectly recovered for further processing of the frame, it can be used as a new reference for channel estimation. Note that a first estimate of the channel will be always required to process FC symbol. To the best of the authors knowledge, no reports exist in the literatura where the impact of this approach is evaluated in presence of narrow band noises, which in the following is analyzed through simulations.

The remainder of this paper is organized as follows. Section II presents the transceiver employed, as well as the channel and noise models. The proposed method and an analysis of its performance are addressed in Section III. Finally, conclusions are drawn in Section IV.

II. SYSTEM MODEL

The transceiver employed in this work was designed according to the specifications of IEEE Standard 1901-2010. Fig. 1 shows a block diagram of the system. The forward error correction (FEC) block is constitued by a data scrambler, a turbo convolutional encoder and a channel interleaver. Later, a QPSK mapper followed by an inverse fast Fourier transform (IFFT), conform the time domain symbols. Higher order QAM modulation can be used in the mapper. Then, a cyclic prefix (CP) is inserted. This prevents intersymbol interference due to the passage of the signal through the channel, and allows a further simple frequency-domain processing.

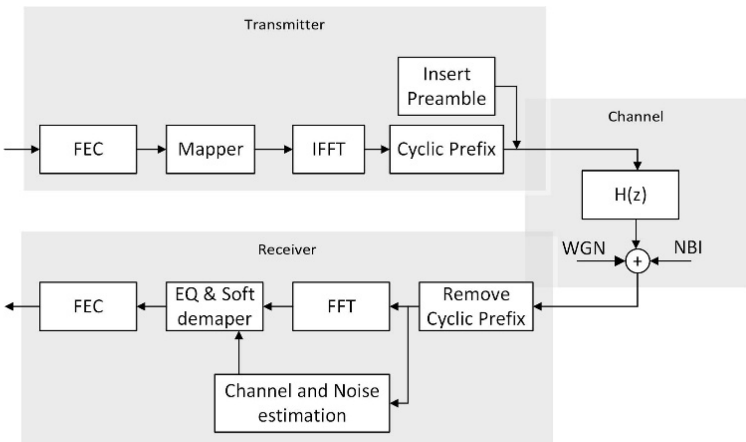


Fig. 1 FFT transceiver

According to [6], *PHY protocol data units*

(PPDU) carrying payload are constituted by a preamble sequence, at least one FC symbol and payload symbols [1, Table 13-3]. Based on preamble knowledge, the receiver performs detection, synchronization and channel estimation. Even when different combinations are possible, the 1901 FFT preamble and one 1901 FFT FC symbol are always present in every PPDU. The FC symbol carries frame control information like modulation type and order per carrier, code rate, guard interval values, etc. This makes mandatory its perfect recovery. When the checksum error algorithm detects the occurrence of errors in FC symbol, the frame is immediately discarded. Therefore, a new perfectly known reference can be created in the receiver. This characteristic is exploited in this work to improve the channel estimation.

The two processes that conform the channel estimation will be henceforth differenciated for a better understanding: CFR estimation and NPSD estimation. While channel estimation will be employed for referring to both estimations.

The channel response is modeled according to the multipath model proposed by Zimmerman in 2002 [9]. White gaussian noise (WGN) and a narrow-band interfering signal (NBI) are added as it is shown in the channel block. After removing the CP, the signal at the input of the FFT block can be modeled in the frequency domain according to (1).

$$Y(k) = H(k)X(k) + N_{WGN}(k) + N_{NBI}(k) \quad (1)$$

Where k = 0, 1, … 2047 is the subcarrier index, H is the channel frequency response, X is the received signal and N_{WGN} and N_{NBI}, are white Gaussian noise and narrow-band noise, respectively. In general, NB interferences are provoqued by broadcasters in long, middle and short wave range as well as several radio services. It can be modeled in the time domain as a sum of multiple sine signals with different amplitudes ($A_i(t)$) and frequencies (f_i) (2),

$$n_{NBI}(t) = \sum_{i=1}^{I} A_i(t) \cdot \sin(2\pi f_i t + \varphi) \quad (2)$$

$i = 1, 2, \dots, I$ is the interference index and I is the number of interferences.

III. Channel and Noise estimation by FC symbol re-encoding and re-mapping

The 1901 FFT preamble is composed of 10 OFDM minisymbols each consisting of 256 subcarriers. On the other hand 1901 FFT FC and payload OFDM symbols consist of 2048 subcarriers. Result of preamble-based channel estimation must therefore be extrapolated from 256 frequency points to 2048 frequency points for equalization and later decoding. This extrapolation broadens the narrow-band noises in the non-observed subcarriers, causing a wrongly compensation of the signal at the input of the turbo decoder. The FC OFDM symbol, being restricted to the use of quaternary phase-shift keying, may be used to refine the preamble-based channel estimates. However, another application of the LMMSE estimator incurs high computational costs, leads to delays and may be unfeasible in real-time systems.

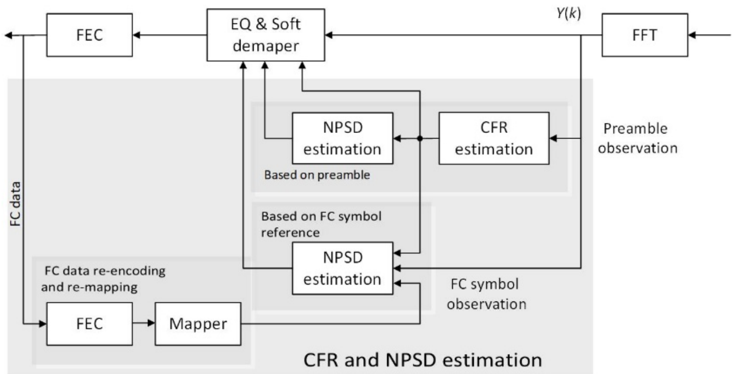


Fig. 2 CIR and NPSD estimation based on FC symbol re-encoding and re-mapping

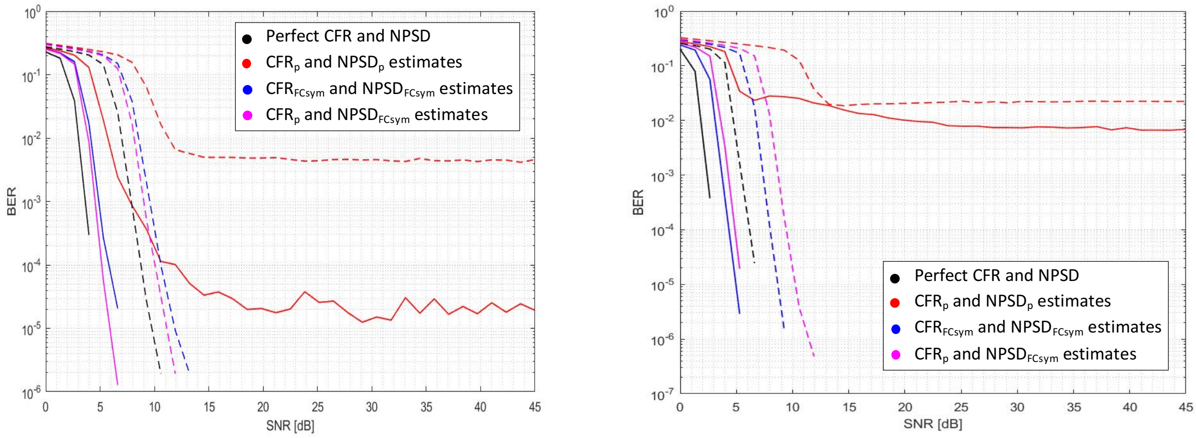
A more suitable alternative is to use the FC symbol for improving only the NPSD estimate, which is crucial to cope with narrow band interferers. Fig. 2 shows a block diagram of the proposed channel estimation method, including an improvement of the NPSD estimates by re-encoding and re-mapping the FC symbol. A sequential analysis of our proposal is done in the following algorithm.

Channel estimation method based on FC symbol re-encoding and re-mapping

1. Estimate the CFR and the NPSD based on the preamble sequence.
2. Recover FC bits.
3. ***IF*** Checksum error ***THEN***
4. Discard the frame.
5. ***ELSE***
6. Re-encode and re-map FC bits in order to obtain a new reference.
7. Re-estimate the NPSD based on the FC symbol.
8. Equalize the payload symbols with the preamble-based CFR estimate.
9. Compute the log-likelihood ratios for the bits in the payload and the FC symbol-based NPSD estimate.
10. Decode payload.
11. ***END***

The system was tested with flat-fading channel (solid lines) and a multipath channel (reference channel 2 of *OPERA deliverable D4* [8, p. 50] (dashed lines). Experiments were performed with one (Fig. 3) and three in-band NBI signals (Fig. 4). Signal-to-jamming power ratio (SJR) was chosen -25dB (according to the *Immunity to narrowband interference* specification in [6, Section 13.11.3]) for both experiments.

Red lines show the bit-error rate (BER) curves for preamble-based channel estimation. Magenta curves show the performance of our proposal; that is, preamble-based CFR estimation combined with FC symbol-based NPSD estimation. While blue curves result from FC symbol-based channel estimation. It is apparent that system performance improves substantially when FC symbol reference is used. However, there is no significant improvement from updating the CFR estimation based on FC symbol.



a.) one NBI tone b.) three NBI tones

Fig. 3 BER for flat-fading channel (continuous lines) and a multipath channel (dashed lines)

IV. Conclusions

The performance of PLC systems building on the IEEE Std. 1901 can be substantially enhanced by utilizing the FC symbol to improve the channel frequency response estimate and the noise power spectral density estimate, especially in the presence narrow-band interference. The obtained gains are due to the higher frequency resolution of the FC signal observation as compared to the preamble. It has further turned out that a re-estimation of only the NPSD (and not CFR) is sufficient. This proposal have the advantage of being feasible for practical systems and will not lead to high computational costs or delays.

V. References

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VI. Acknowledgments

The research leading to these results has partially received funding from the Swiss Federal Office of Energy (BFE) and the Swiss Hasler Foundation.