

Impulse Noise Suppression for G.hn Broadband Power-Line Communication in Smart Grid

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Abstract—Power-line communication (PLC) system can exchange information over the existing electrical grid without much extra implementation cost. Such system will play an important role in the future Smart Grid. However, the system performance of PLC systems will be severely degraded by the multipath fading and random impulse noise (IN). This paper intends to evaluate the performance of different IN detection and reduction schemes combined with low-density parity check (LDPC) decoding for the PLC systems based on G.hn (Gigabit Home Networking) specification. In particular, to improve the system performance, we modify the likelihood value calculation of the LDPC decoder with the information of signal-power and noise-power change due to the process of IN reduction and equalizer.

Keywords—*Broadband PLC, Multipath fading, Impulse noise, Error-Correcting-code, LDPC*

I. INTRODUCTION

With the rapid development of internet of things (IoT), power-line communication (PLC) has recently attracted considerable attention for transmitting high-speed data. This technology exploits the ubiquitous power-line infrastructure and holds the advantage of plug-and-play with low cost to provide broadband multimedia services.

However, the power-line infrastructure is not a friendly channel for data transmission. The channel characteristic includes time-various multipath fading due to changeable load topology and a variety of noise interferences. Among them, the random impulse noise (IN) is a key problem to the system. Impulse noise can mainly be divided into two categories: memoryless [1-4] and bursty (with memory) [5-10]. The latter means the impulse noise is correlated with each other.

Several simple nonlinear schemes to mitigate the impact of impulse noise have been proposed, including clipping [11-12], blanking [13-14], and hybrid [15-17] schemes. For all these schemes, the setting of threshold values (TH) is critical. [15-17] determined the thresholds by simulations and [18] got the threshold value by a pre-determined false alarm probability.

As regards the performance comparison of these three simple schemes, the hybrid one is the best and the blanking scheme is better than the clipping scheme [16]. However, the hybrid scheme needs two thresholds which cannot be determined by a simple way with a pre-determined false alarm probability. Hence, this work adopts blanking scheme, instead of hybrid one, as the simple IN detection/reduction process.

Although the above three schemes are simple, the blanking (or clipping) process will reduce the received signal power and destroy the orthogonality of the OFDM signal, which results in inter-carrier interference (ICI) [19]. Hence, an iterative approach, called Häring (H)-iterative scheme or Mengi-Häring (MH)-iterative scheme, which can ideally cancel the IN without ICI and signal-energy loss, was proposed in [20, 21]. The iterative IN suppressing schemes perform well. However, besides the high complexity, such schemes will suffer from the error propagation at low SNR.

Nowadays, the G.hn (Gigabit Home Networking) G.9960 specifications [22-23] is the main standard for the broadband PLC systems. Besides the OFDM signal of a total 50-100MHz bandwidth, this standard adopts the low-density-parity-check (LDPC) code for error-correction. Based on G.hn specification, this work intends to evaluate the system performance of different IN detection/reduction (or suppressing) algorithms combined with the LDPC decoding for the broadband PLC systems.

In the performance evaluation process, this work studies a combined structure of iterative IN-suppressing scheme and LDPC decoder to reduce the error propagation. To further improve the system performance, the likelihood value calculation in the LDPC decoding is modified with the

information of signal-power and noise-power change due to the processes of IN-reduction and equalizer. Moreover, to suppress the bursty impulse noise, we adopt the interleaver specified in G.hnem G.9955 (for narrowband PLC).

The rest of this paper is organized as follows. Section II depicts the system model adopted in this work, including power-line channel and impulse noise model. The conventional IN detection/reduction schemes are described briefly in Section III. In Section IV, several novel designs to improve the system performance are proposed. Section V shows the performance evaluation of different schemes. Finally, Section VI concludes this paper.

II. SYSTEM MODEL

G.hn is a physical layer specification for broadband PLC. This standard adopts OFDM modulator to transmit data and LDPC code for error correction. Fig. 1 depicts the block diagram of G.hn system [22]. The transmitted signal s passes through a power line channel, corrupted by background noise (w) and impulse noise (i). The received signal can be expressed as

$$r = s * h + w + i, \quad (1)$$

where $*$ denotes the convolution operation and h is the impulse response of the PLC channel.

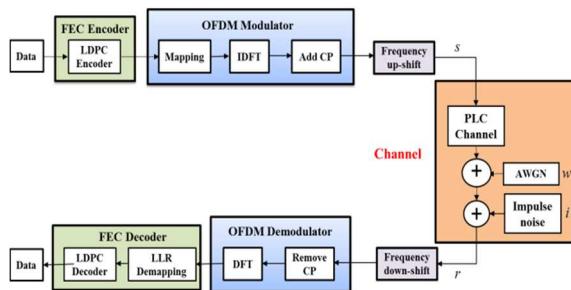


Fig. 1. Block Diagram of G.hn system

A. Power-Line Channel Model

The multipath model for power line channels proposed by Zimmerman [24] is adopted in this study. The frequency response of the multipath model is

$$H(f) = \sum_{i=1}^{N_{paths}} g_i(f) e^{-\alpha(f)d_i} e^{-2\pi f \theta_i} \quad (2)$$

where N_{paths} denotes the number of the paths, $g_i(f)$ is the weighting factor, $\alpha(f)$ is the attenuation parameter, d_i is the length, and θ_i is the delay associated with the i -th path. To compensate the impact of PLC channel, the least-square (LS) equalizer with the assumption of perfect channel estimation is employed in the following performance evaluation.

B. Impulse Noise Model

In the PLC environment, data transmission may suffer from various types of noises, including colored background noise, periodic impulsive noise, and asynchronous impulsive noise. Among these noises, the asynchronous IN is the key problem to the system. Hence, this paper is devoted to evaluate the impact of IN in broadband PLC systems, with the assumption that background noise is additive white Gaussian noise (AWGN) with zero mean and variance σ_w^2 .

The asynchronous IN can mainly be divided into two categories: independent and bursty. The independent IN is usually described by a Bernoulli-Gaussian (BG) model [3-6] or Middleton Class-A mode [27]. This study adopts the BG model in which the probability density function (PDF) of IN is

$$\begin{aligned} & f(x | \sigma_w^2, \sigma_i^2, P_{impulse}) \\ &= \frac{1 - P_{impulse}}{\sqrt{2\pi\sigma_w^2}} \exp\left(\frac{-x^2}{2\sigma_w^2}\right) + \frac{P_{impulse}}{\sqrt{2\pi(\sigma_w^2 + \sigma_i^2)}} \exp\left(\frac{-x^2}{2(\sigma_w^2 + \sigma_i^2)}\right), \end{aligned} \quad (3)$$

where σ_i^2 is the variance of impulse noise, and $P_{impulse}$ is the occurrence probability of IN. Particularly, we define $\mu = \sigma_i^2 / \sigma_w^2$ as the IN power to background noise power ratio.

The bursty impulse noise is usually modelled by two-state Markov Model [10, 25-26] as shown in Fig. 2. For this paper, the values of transition probabilities p and q are derived from the measured data shown in [10].

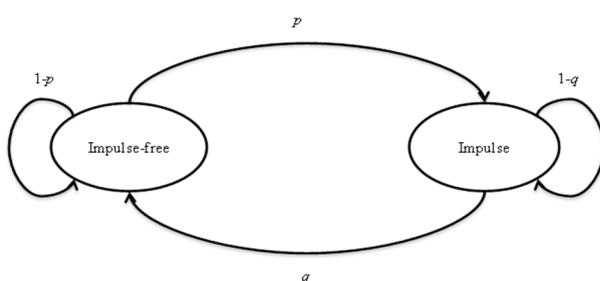


Fig. 2. Two-State Markov Model for Bursty Impulse Noise

III. IMPULSE NOISE PROCESSING

To detect and reduce (suppress) the asynchronous impulsive noise, this paper adopts two schemes, including blanking and MH-iterative scheme. Fig. 3 shows the system block diagram with IN process.

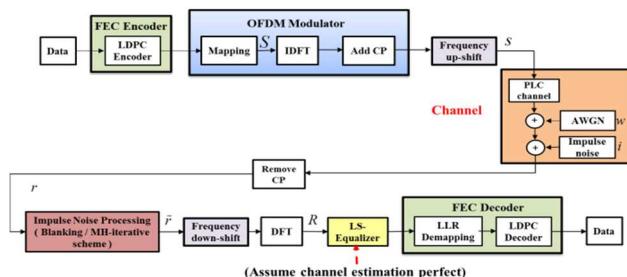


Fig. 3. System Block Diagram with IN Processing

A. Blanking scheme

The Blanking process is defined as

$$\%_0 = \begin{cases} r & \text{for } |r| < Th \\ 0 & \text{for } |r| > Th \end{cases}, \quad (4)$$

To determine the threshold Th , we utilize the idea of Neyman-Pearson test [18] that, given a pre-defined false alarm probability P_{false} , Th can be derived by

$$P_{false} = 2 \cdot \int_{Th}^{\infty} f(x|h_{free}) dx, \quad (5)$$

where

$$f\left(x \mid h_{free}\right) = \frac{1}{\sqrt{2\pi(\sigma_s^2 + \sigma_w^2)}} \exp\left(-\frac{x^2}{2(\sigma_s^2 + \sigma_w^2)}\right). \quad (6)$$

Here, σ_s^2 is the power of the received signal. Note that, because the received r is a real signal on the PLC channel instead of a

complex signal on the wireless channel, $f(x|h_{free})$ is modeled by Gaussian distribution.

B. MH-iterative scheme

Refer to [17, 20], the block diagram for the MH-iterative scheme is shown as Fig. 4. A simple blanking process is employed for the initial IN-process of the received signal r . The detection of impulse noise is defined as

$$\hat{y}_0 = \begin{cases} \hat{n} & \text{for } \hat{n} > th \\ 0 & \text{for } \hat{n} < th \end{cases}, \quad (7)$$

where the threshold th is set to $th = c \times \sigma_w$ as proposed in [20]. The c constant factor itself is a subject to be optimized by the help of a brute-force search with respect to the BER.

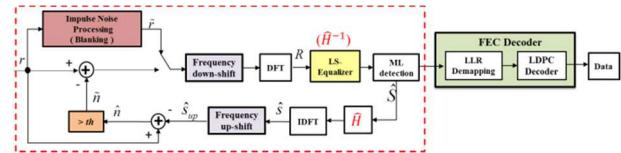


Fig. 4. Block Diagram of the Receiver with MH-Iterative Scheme [20]

IV. PERFORMANCE IMPROVEMENT

To improve the system performance, this work proposes three methods as follows.

A. Combined Structure

As mentioned before, the MH-iterative scheme suffers from the error propagation. To combat this drawback, it is proposed that the LDPC decoder is integrated into the iterative structure. The block diagram of the modified iterative receiver is depicted in Fig. 5.

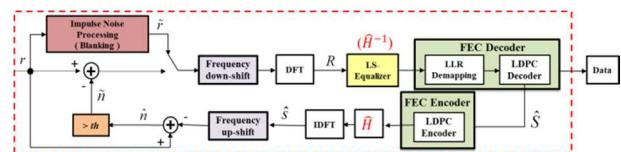


Fig. 5. Block Diagram of the Receiver with Combined Structure

B. LLR-value calculation

The sum-product algorithm or min-sum algorithm is typically employed for the soft decoding of LDPC codes. The

likelihood value used in the soft decoding is calculated by

$$\frac{1}{\sqrt{2\pi\sigma_w^2}} \exp\left(-\frac{|R-S|^2}{2\sigma_w^2}\right), \quad (8)$$

where R is the received signal, S is the transmitted signal and σ_w^2 is noise power.

However, because the IN-blanking process will reduce the signal power and generate extra ICI [19], both the transmitted signal S and noise power σ_w^2 of (8) should be modified. According to [29], the modified transmitted signal is

$$S' = \sqrt{\frac{K_{even}^2 + K_{odd}^2}{2}} S, \quad (9)$$

where $K_{even/odd} = \frac{N - m_{even/odd}}{N}$, $m_{even/odd}$ is the number of

impulse noise detected at the even/odd sampling points. The modified noise power is

$$\sigma_z^2 = K_{even} E\left[\left|W_{even}\right|^2\right] + \left(K_{even} - K_{even}^2\right) E\left[\left|S_{even}\right|^2\right] + K_{odd} E\left[\left|W_{odd}\right|^2\right] + \left(K_{odd} - K_{odd}^2\right) E\left[\left|S_{odd}\right|^2\right], \quad (10)$$

where $W_{even/odd}$ represents the background noise at even/odd sampling points, and $S_{even/odd}$ represents the transmitted signal at even/odd sampling points.

Moreover, as mentioned before, if perfect channel estimation is assumed and a least-square (LS) equalizer is employed at the receiver, the noise power in the likelihood-value calculation should be further modified as $\frac{\sigma_z^2}{|H_k|^2}$, where H_k is frequency response at k to sub-channel.

In summary, the likelihood value calculation for the soft decoding becomes

$$\frac{1}{\sqrt{2\pi\left(\frac{\sigma_z^2}{|H_k|^2}\right)}} \exp\left[-\frac{\left|R - \sqrt{\frac{K_{even}^2 + K_{odd}^2}{2}} S\right|^2}{2\left(\frac{\sigma_z^2}{|H_k|^2}\right)}\right]. \quad (11)$$

C. Bursty Impulse Noise

From the performance evaluations which are shown in the next section, it can be seen that the bursty IN will severely damage the system even with IN process and LDPC decoding. Hence, this work proposes to add an interleaver-deinterleaver, which does not appear in the G.hn G.9960 specifications, to combat bursty IN. The interleaver adopted in this work is just the interleaver defined in G.hnem G.9955 specifications (for narrowband PLC) [28]. The system block diagrams with interleaver/deinterleaver are shown in Fig. 6.

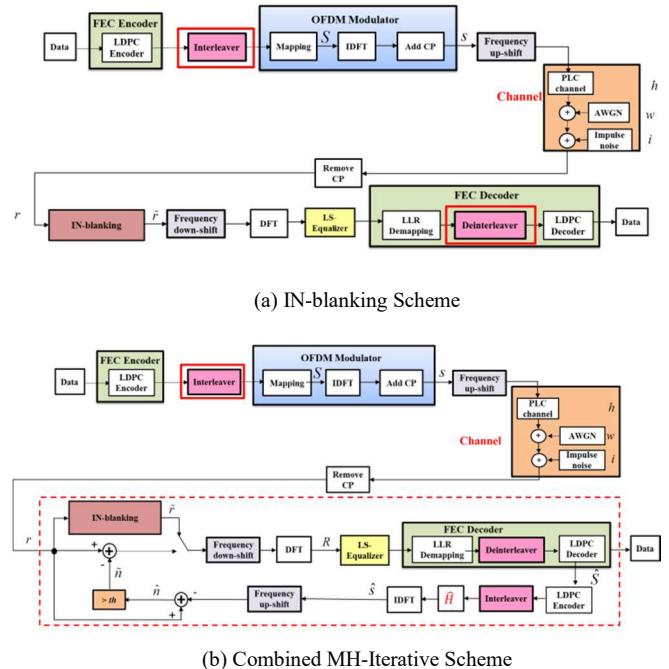


Fig. 6. System Block Diagram with Interleaver/Deinterleaver

V. SIMULATION RESULTS

To evaluate the performance of the proposed algorithms, we set up a simulation performance based on the specifications of G.hn G.9960 [22] for the broadband PLC. Perfect synchronization and LS equalizer with perfect channel estimation also assumed.

Some key parameters used in the simulation system are as follows:

- Modulations scheme: 16QAM
- Sampling Frequency (f_s): 50 MHz
- FFT Size (N): 2048
- Cyclic Prefix Length (N_{cp}): 512
- LDPC Code: (N_{FEC}/K)=8640/4320 as defined in G.hn Spec. [22]
- Block Interleaver: as defined in G.hnem Spec. [28]
- False Alarm Probability (\mathcal{Th}) for IN blanking scheme: 10^{-4}
- IN occurrence Probability ($P_{impulse}$): 0.0033 for the heavy IN environment as defined in [10]
- Bursty IN: (p, q)=($5.1 \times 10^{-7}, 1.56 \times 10^{-4}$) for the heavy IN environment as defined in [10]
- μ for IN: 1000

For the performance evaluation, this work classifies different system designs into several algorithms according to the employed processes:

- Alg. 1: A simple IN-blanking process with LDPC code (as Fig. 3).
- Alg. 2: As Alg. 1, but with modified likelihood value.
- Alg. 3: As Alg. 1, but with interleaver/deinterleaver (as Fig. 6(a)).
- Alg. 4: As Alg. 2, but with interleaver/deinterleaver.
- Alg. 5: MH-Iterative IN-process with LDPC decoder (as Fig. 4).
- Alg. 6: Combined MH-Iterative IN-process with LDPC decoder (as Fig. 5).
- Alg. 7: As Alg. 5, but with modified likelihood value.
- Alg. 8: As Alg. 6, but with modified likelihood value.
- Alg. 9: As Alg. 5, but with interleaver/deinterleaver.
- Alg. 10: As Alg. 6, but with interleaver/deinterleaver (as Fig. 6(b)).
- Alg. 11: As Alg. 7, but with interleaver/deinterleaver.
- Alg. 12: As Alg. 8, but with interleaver/deinterleaver (as Fig. 6(b))

A. Independent Impulse-Noise Environment

Fig. 7 shows the system performance comparison among different algorithms for the PLC channel with independent impulse noise. From this figure, it can be seen that Alg. 8 is the best system design. However, Alg. 2 can offer a system performance close to Alg. 8, but with a much simpler process. It is also observed that, with modified likelihood value, there is

a 12 dB gain (Alg. 1 vs. Alg. 2) and, with the proposed combined structure of MH-iterative IN process and LDPC decoder, there is a 4 dB gain (Alg. 7 vs. Alg. 8).

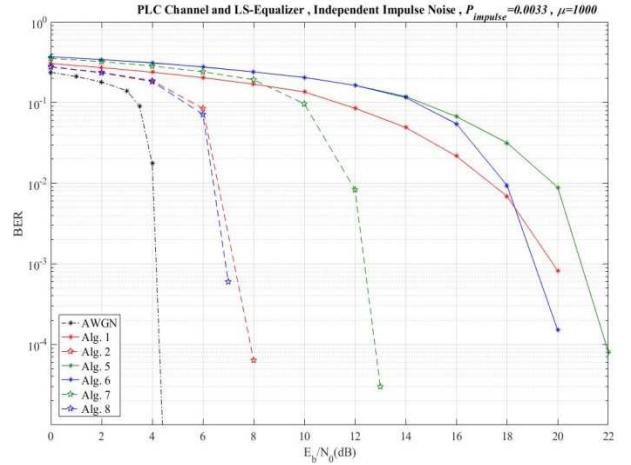


Fig. 7. System Performance Comparison for Independent IN Environment

B. Bursty Impulse-Noise Environment

Fig. 8 shows the system performance comparison among different algorithms for the PLC channel with bursty impulse noise. From this figure, it can be seen that Alg. 12 is the best system design. However, Alg. 4 can offer a system performance close to Alg. 12, but with a much simple process. It can also be observed that, for Bursty IN environment, the performance of the system design without interleaver/deinterleaver is much worse than that with interleaver/deinterleaver.

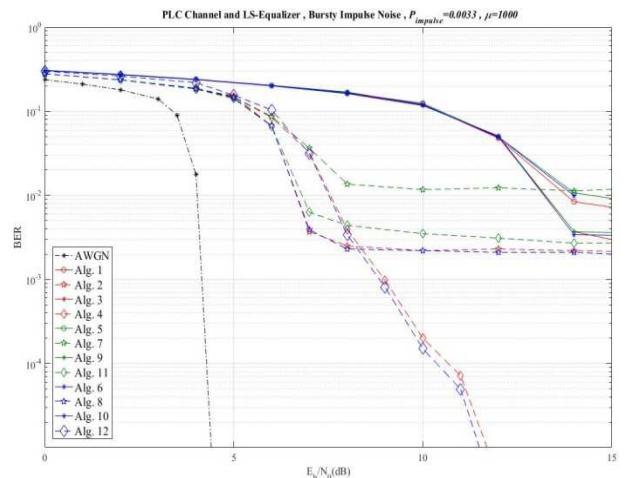


Fig. 8. System Performance Comparison for Bursty IN Environment

VI. CONCLUSION

This paper is devoted to the performance evaluation of different designs for G.hn broadband PLC system under asynchronous impulse noise channels. It is shown that the performance can be improved by modifying the likelihood-value calculation, which considers the signal power reduction and ICI generation of IN-blanking process and the noise-power change of the LS equalizer. For the bursty IN, we further adopt an interleaver to disperse the noise. As a result, it can be seen that the performances of Alg. 8 and Alg. 12 are the best for the independent IN channel and bursty IN channel, respectively. It can also be seen that Alg. 2 and Alg. 4 can offer almost the same performance as the best ones. If we consider the complexity, Alg. 2 and Alg. 4 may be a good choice for the system design.

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