Improving Performance of the MH-Iterative IN Mitigation Scheme in PLC Systems

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Abstract—We call the Häring-iterative scheme with the clipping-nulling scheme as the preprocessing impulsive noise (IN) mitigation scheme: Mengi-Häring (MH)-iterative scheme. In this paper, we report two ideas that can significantly improve its performance. The first idea is to use the replacement-nulling scheme as the preprocessing IN mitigation scheme. The second idea is to use the output vector of the preprocessing IN mitigation scheme in all iterations. To show the performance comparison between the MH-iterative scheme and our proposed scheme, we conduct some simulations in the simplified model of the Middelton’s additive white class A noise model and present performance in terms of the bit-error rate as a function of the signal-to-noise ratio.

Index Terms—Impulsive noise, iterative impulsive noise mitigation scheme, orthogonal frequency-division multiplexing (OFDM).

I. INTRODUCTION

T
HE USE of the power-line channel (PLC) as a communication medium is an interesting idea. However, the PLC is not a friendly channel for information delivery. It has many problems, such as signal attenuation, narrowband interference, and also impulsive noise (IN). We present a solution for handling degradation in performance of orthogonal frequency-division multiplexing (OFDM)-based transmission caused by the presence of IN.

The research direction of the IN mitigation schemes for OFDM is basically divided into two categories: 1) parametric and 2) nonparametric IN mitigation schemes. The parametric scheme requires the knowledge of IN parameters, while the nonparametric does not require any knowledge of the IN parameters. Thus, the benefit of the nonparametric IN mitigation scheme over the parametric scheme is that it can be used on different IN channel models.

The basic idea of a parametric scheme, which is a threshold-based approach, can be divided into two parts: 1) determining the threshold value to be used and 2) determining the action to be taken. Only the first part—the determination of the threshold value to be used—requires the full [1] or partial [2] knowledge of the IN parameters. The second part, on the other hand, requires no knowledge of the IN parameters. Therefore, when the first part of a parametric scheme is designed to not depend on the IN parameters, the parametric scheme has been turned into a nonparametric scheme. Some recent publications on the nonparametric IN mitigation schemes for OFDM systems are in [3]–[5].

The two categories of the IN mitigation schemes mentioned before can be further divided into two types: 1) iterative and 2) noniterative schemes. The difference between these two types is the use of a feedback mechanism that allows iterative IN mitigation processes: an output of the i-th IN mitigation process is used as an input of the (i + 1) th mitigation process. An iterative scheme uses the feedback mechanism whereas a noniterative scheme does not use it.

This paper focuses on ideas to improve a known iterative IN mitigation scheme for an OFDM system, called the Mengi-Häring (MH)-iterative scheme [1]. The MH iterative scheme is an extension of the Häring (H)-iterative scheme [6], where the clipping-nulling (CN) scheme [7] is added as a preprocessing IN mitigation scheme. The use of the preprocessing IN mitigation scheme is to increase the reliability of the first noise estimate by reducing IN power. This simple idea is an interesting idea since it improves the performance of the H-iterative scheme while maintaining low complexity in the receiver design. However, we notice that the structure of the MH-iterative scheme allows the use of unreduced IN power in the IN iterative mitigation process, which reduces the reliability of the noise estimate in the following iterations.

In this paper, we show two ideas that can improve the performance of the MH-iterative scheme significantly. First, there is the modification of the MH-iterative scheme structure, so that the IN power is reduced in all IN iterative mitigation processes and, therefore, good reliability of the noise estimate can be preserved in all iterations. Second, we show that the use of the replacement-nulling (RN) scheme, such as the preprocessing IN mitigation scheme, instead of the CN scheme, will bring additional performance improvement.

The rest of this paper is organized as follows. Section II explains the system model used. In Section III, the MH-iterative scheme will be explained, whereas in Section IV, we present the proposed ideas. Sections V and VI report the simulation results and conclude this paper.

II. SYSTEM MODEL

An OFDM system is a pair of inverse discrete Fourier transforms (IDFTs) and discrete Fourier transforms (DFTs). The IDFT is commonly used at the transmitter side, while the DFT is used at the receiver side.


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The IDFT at the transmitter side is used to generate the time-domain OFDM samples $x_n$, or the complex baseband transmitted signal, from baseband symbols $X_k$ as follows:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi nk/N}$$

(1)

where $N$ is the number of OFDM subcarriers, $X_k$ is a baseband symbol, and $x_n$ is the same length as $X_k$.

At the receiver side, the DFT is then used to transform the received time-domain OFDM samples $r_n$ to its frequency-domain representation. It is obvious that if the received time-domain OFDM samples are noiseless, that is, $r_n = x_n + n_n$, where $n_n$ is the additive noise sample and $n_n \sim 0$, then the output of the DFT is basically the transmitted baseband symbols $X_k$.

$$X_k = \sum_{n=0}^{N-1} r_n e^{-j2\pi nk/N}.$$  

(2)

If $r_n$ is noisy, that is, $n_n \neq 0$, then an additional step such as, for example, maximum-likelihood (ML) estimation is needed to obtain the approximation $U_k$ of the transmitted baseband symbols $X_k$.

The MIH-iterative scheme and, thus, our proposed scheme uses the combination between IDFT, DFT, and the ML estimation to form the IN iterative mitigation process at the receiver side as will be discussed in Sections III and IV.

To simplify simulations and analysis, we use the simplified model of the Middleton’s additive white class A noise (AWCN) model to describe the presence of the noise (Fig. 1). This model is also called the two-state IN channel model and can be seen as a simplified PLC channel model (see also [9]).

The AWCN model was also used in [1] and [6] and, therefore, it is sufficient to be used to show a fair comparison between the MIH-iterative scheme and the proposed scheme.

### III. MIH-ITERATIVE SCHEME

Fig. 2 shows the blocks diagram of the MIH-iterative scheme, which works as follows.

In the zeroth iteration, $l = 0$, the CN scheme is used to do preliminary IN mitigation. Its result, vector $\tilde{r}$, is then used as an input to the DFT. In the next iterations, $l > 0$, where the vector $\tilde{r}$ is not used anymore, the following steps are applied.

In every iteration $l > 0$, the better approximation of the transmitted time-domain OFDM samples vector $r^{(l+1)}$ are transformed to the frequency-domain representation with the help of the DFT. After that, the ML estimation is used to approximate transmitted baseband symbols $U^{(l)}$. The noise vector $n^{(l)}$ in the received samples vector $r$ (or $r^{(l)}$) is defined as $n^{(l)} = r^{(l)} - c^{(l)}$, where $c^{(l)}$ is the representation of $U^{(l)}$ in the time domain. The detection of the components in $n^{(l)}$, which are the IN $\tilde{n}^{(l)}$, is done in the time domain with the help of a threshold $Thr$ as follows:

$$\tilde{n}^{(l)} = \begin{cases} 0, & \text{for } n_i^{(l)} \leq Thr \\ n_i^{(l)}, & \text{for } n_i^{(l)} > Thr \end{cases}$$

(3)

The input vector for the next iteration is defined as $r^{(l+1)} = r^{(l)} - \tilde{n}^{(l)}$.

Having the mechanism explained, the scheme is expected to improve $U^{(l)}$ (or $c^{(l)}$) in every iteration, so that the approximation of the noise $n^{(l)}$ becomes more accurate.

As can be noticed, the structure of the MIH-iterative scheme allows the use of reduced IN power in the IN iterative mitigation process. This leads to a reduction in the reliability of the noise estimate in the following iterations, since the IN variance strongly influences the calculation of the threshold $Thr$. The detailed discussion on this topic is covered in Section V-B. Therefore, in the next section, we propose a modification to the MIH-iterative scheme structure as a solution to this problem. We also explain the motivation of replacing the CN scheme with the RN scheme as the preprocessing IN mitigation scheme.

### IV. PROPOSED MODIFICATION

The proposed modifications of the MIH-iterative scheme are described using Fig. 3.
A. First Modification: We Use the RN Scheme as the Preprocessing IN Mitigation Scheme

In [3], we introduced the replacement (R) scheme and showed that it delivers better performance than the C scheme. Therefore, our first proposed modification is to use the combination between the R scheme and the N scheme, forming the replacement-nulling (RN) scheme, instead of the combination between the C scheme and the N scheme, as the preprocessing IN mitigation scheme. The decision of the RN scheme is as follows:

\[
\hat{r}_n = \begin{cases} 
    r_n, & \text{for } |r_n| \leq T_{rep} \\
    \bar{x}|r_n|, & \text{for } T_{rep} < |r_n| \leq T_{null} \\
    0, & \text{for } |r_n| > T_{null}
\end{cases}
\]  (4)

where \( \hat{r}_n \) is the sample that is obtained after the mitigation process, and \( \bar{x} \) is the average magnitude of the OFDM noiseless samples

\[
\bar{x} = \sqrt{\frac{2 \times \sigma_S^2}{s}}
\]  (5)

where \( \sigma_S^2 \) is the variance of the transmitted signal. The replacement threshold and the nulling threshold are defined as \( T_{rep} \) and \( T_{null} \), respectively.

B. Second Modification: We Use \( \hat{r} \) in All Iterations

The second modification is to use the vector \( \hat{r} \) in all iterations instead of only in the zeroth iteration as the MH-iterative scheme does. In this way, we limit the power spectral density (PSD) of the IN \( \sigma^2 \) in the received samples vector \( r \) that will be used in all iterations.

Now, we discuss the basic reason of using a preprocessing IN mitigation scheme in the zeroth iteration, \( \hat{r} = 0 \), and its relation to the next iterations \( \hat{r} = 0 \). When a sample \( r_n \) is detected as being corrupted by the IN, then the preprocessing IN mitigation scheme changes the magnitude of the corrupted samples to a ‘better’ magnitude based on its rule: for the R scheme, the ‘better’ magnitude is \( |\bar{x}| \) whereas for the N scheme it is zero. The ‘better’ magnitude can be further improved by replacing it with the output of the IDFT on every iteration, \( c_k \). We assume that \( c_k \), which is the approximation of the transmitted OFDM noiseless samples in iteration \( i \), gets better from iteration to iteration. Therefore, in the set of positions \( P \) where the preprocessing IN mitigation scheme has been applied, we set \( T_{hr} = 0 \). As a result, \( \hat{r}^{(i+1)}_n = r^{(i)}_n - \hat{r}^{(i)}_n = c^{(i)}_k \), where \( i \in P \). For other positions \( k \notin P \) in which the preprocessing IN mitigation scheme has not been applied, the following situations occur:

1) \( c^{(i)}_k \) is the correct estimate of the transmitted sample.

Let \( x_k \) be the correct transmitted sample and \( n^{(i)}_k = x_k + n_k \), where \( n_k \) is a noise component. Thus, in this case the \( r^{(i)}_k = x_k - c^{(i)}_k \) contains only the underlying background noise or the IN. The input vector for the next iteration \( r^{(i+1)}_k \) is then decided as follows:

\[
\hat{r}^{(i+1)}_k = \begin{cases} 
    r^{(i)}_k, & \text{for } n^{(i)}_k < T_{hr} \\
    c^{(i)}_k, & \text{for } n^{(i)}_k > T_{hr}
\end{cases}
\]  (6)

It is important to notice that when \( n^{(i)}_k < T_{hr} \), the basic iterative algorithm takes the corrupted transmitted sample \( r^{(i)}_k \) instead of the correct transmitted sample itself \( c^{(i)}_k \). This means it might degrade the performance at high SNR.

2) \( r^{(i)}_k \) is the incorrect estimate of the transmitted sample.

In this case, there is additional noise \( e^{(i)}_k = x_k - c^{(i)}_k \) which is called wrong decision noise. The input vector for the next iteration \( r^{(i+1)}_k \), on the other hand, remains the same as given in (6).

V. SIMULATIONS AND DISCUSSIONS

We simulate QPSK-256OFDM uncoded transmission (see Fig. 4) with variance of the transmitted signal \( \sigma^2 = 1 \). The two-state IN channel model as explained in Section II is used. When a preprocessing IN mitigation scheme, such as the CN or the RN scheme is used, the threshold setting is \( T_{cmin} = 2.2 \sigma^2 \) and \( T_{null} = 1.4T_{cmin} \) [1]; \( T_{rep} = T_{cmax} \).

In [6], the threshold used to detect the location of the IN in \( n^{(i)}_k \) is defined as \( T_{hr} = c \times \sigma^2 \), where \( c \) is a constant factor and \( \sigma^2 \) is the variance of the statistical-independent noise caused by wrong decisions made by the detect operator. However, by using a threshold, which is a function of only, the wrong decision variance is not practical, since it requires the knowledge of the transmitted samples (see Section IV.B.2). Therefore, in simulations, we consider the threshold \( T_{hr} \) which is a function of the noise variance in each iteration \( l \), \( T_{hr} = c \times \sigma^2 \), and it can be calculated from the vector \( n^{(i)}_k \). The constant factor \( c \) itself is a subject to be optimized with the help of a brute-force search with respect to the BER.

A. Simulation 1: Is the Use of the RN Scheme as the Preprocessing IN Mitigation Scheme a Good Idea?

This simulation is to show the performance of the Häring-iterative scheme when the output of a preprocessing IN mitigation scheme is used in the zeroth iteration only (Meng’s idea [11]). Two different simple IN mitigation schemes will be considered, the clipping-nulling (CN) scheme (the MH-iterative scheme idea) and the replacement-nulling (RN) scheme (our first idea, see Section IV-A).
The threshold setting for $T_{\text{rep}}$, $T_{\text{rep}}$, and $T_{\text{out}}$ follows the explanation in Section V. The threshold $Thr$, which is used to detect the location of the IN, is optimized with the help of a brute-force search (see Figs. 5 and 6). As can be seen, regardless of the type of preprocessing IN mitigation scheme, $Thr = n_0^{(i)}$ is a good threshold for mitigating the IN.

Additional important information that we can see (Fig. 7) is that the use of the RN scheme as the preprocessing IN mitigation scheme shows that it is a good idea to mitigate the IN. In the high-SNR region, however, due to the use of the replacement threshold $T_{\text{rep}}$, which is not good for high SNR [3], the RN scheme delivers worse performance. We will see later (Section V-C), that the high-SNR region problem can be eliminated when we apply our second proposed idea.

B. Simulation 2: Is the Use of the Output of a Preprocessing IN Mitigation Scheme in All Iterations a Good Idea?

First of all, we discuss what actually happens when the output of a preprocessing IN mitigation scheme is used only in the zeroth iteration $l = 0$ and when it is used in all iterations $l \geq 0$.

In the MH-iterative scheme, where the output of the CN scheme is used only in the zeroth iteration, the noise variance in each iteration, $\sigma_n^{(i)}$, depends on the noise variance $\sigma_n^2$, the AWGN variance $\sigma_G^2$ and the IN variance $\sigma_I^2$. In our proposed scheme, however, due to the use of the output of the preprocessing IN mitigation scheme in all iteration $l$, the noise variance $\sigma_n^{(i)}$ depends mainly on the wrong decision variance $\sigma_n^2$ and the AWGN variance $\sigma_G^2$. This can be seen clearly from Fig. 8: in the low-SNR region, where the influence of the IN is strong, the average noise variance in the MH-iterative scheme is high, whereas our proposed system produces almost a flat average noise variance.

The benefit of having the flat average noise variance is that the optimized threshold $Thr$ value, which is a function of the noise variance, can work fine for all SNR. The optimization of the threshold $Thr$ value used in the MH-iterative scheme on the other hand, needs an accurate approximation of the SNR: a different SNR needs a different constant factor $c$. This is a high complexity task and therefore becomes unattractive from a practical point of view.

In this simulation, as it is mentioned in Section V, we use a brute-force search to find a good constant factor $c$ with respect to the BER that will be used in the MH-iterative scheme and our proposed scheme. We find the constant factor $c = 1$ for the MH-iterative scheme while for our proposed scheme, the constant factor $c = 3$. This indicates that the threshold $Thr$ value used in the MH-iterative scheme depends only on the noise variance and therefore it leads to the following consequences: in the low-SNR, the threshold $Thr$ value is too high and in the high-SNR it is too low.

When the threshold $Thr$ value is too high in the low-SNR, then we allow more noisy received samples vector $r$ to enter the next iteration. In the high-SNR, on the other hand, when
the threshold \( T_{hr} \) value is too low then we allow more approximated transmitted samples vector \( c^{(1)} \), which might contain decision errors made by the ML estimation, to enter the next iteration. Based on these two consequences, the MH-iterative scheme is expected to be worse in performance compared to the performance of our proposed scheme (Fig. 9).

C. Simulation 3: Does the Combination of the First and the Second Proposed Ideas Brings the Best Performance?

In our simulations so far, we look at the performance brought by our first idea only and second idea only. We see that each idea provides a positive contribution. In this simulation, we provide the performance of our proposed scheme when both ideas are used. By comparing Fig. 9, in which only the second idea is used, to Fig. 10 where we combine the first and the second ideas, we can see that additional gain can be achieved. We see also that the high-SNR problem introduced by the use of the RN scheme with an inappropriate \( T_{c rp} \) as the preprocessing IN mitigation scheme (see Section VA) is not noticeable.

Another simulation result that we will discuss is the performance of both schemes when the IN power spectral density (PSD) is reduced: we change the IN PSD from \( \sigma_{IN}^2 = 1000\sigma_r^2 \) to \( \sigma_{IN}^2 = 100\sigma_r^2 \). As can be seen in Fig. 11, our proposed scheme performance is still better than the MH-iterative scheme in terms of the BER. However, when we compare the performance of our proposed scheme depicted in Figs. 10 and 11, it is interesting to see that for \( 10 < SNR \leq 20 \)—the SNR-region in which the influence of the IN is still strong—the reduction in the IN PSD is not followed by the reduction in the BER. This is because the number of received samples corrupted by the IN, whose magnitudes are lower than the thresholds used in the preprocessing IN mitigation scheme, increases. As a result, the threshold \( T_{hr} \) value used in our proposed scheme is more influenced by the IN variance (see Fig. 12). Therefore, the increase in the BER is expected.

D. Simulation 4: How Does the Performance of Both Schemes in a Weakly Disturbed Channel Look Like?

In three previous simulations, we discuss the performance of the MH-iterative scheme and our proposed scheme when \( p = 0.1 \) the probability of occurrence of IN in a heavily disturbed channel. In this simulation, we look at the performance of both schemes in a weakly disturbed channel (\( p = 0.01 \)).

In a weakly disturbed channel, the received samples in both schemes are mostly corrupted by the AWGN. The IN in this channel is modelled to have a large PSD. Hence, we can expect improved detection for the preprocessing IN mitigation scheme. This condition implies that there is no need to detect the IN further with the help of the threshold \( T_{hr} \). Therefore, the use of a high threshold \( T_{hr} \) value which allows more received samples \( r_i \), instead of the approximated transmitted samples \( c_i^{(1)} \), to enter the next iteration is preferable. The brute-force search to find a good threshold \( T_{hr} \) value used in our proposed scheme
confirms this situation: we have to increase the threshold \( T_{hr} \) value from \( T_{hr} = 3\sigma_n^2 \) to \( T_{hr} = 5\sigma_n^2 \) in order to have better performance (Fig. 13). In the MH-iterative scheme, however, it cannot be confirmed. The brute-force search gives the same threshold \( T_{hr} \) value, \( T_{hr} = \sigma_n^2 \). Fortunately as it is explained in Section V.B, in the low-SNR region, the threshold \( T_{hr} \) value used in the MH-iterative scheme is already good—\( T_{hr} \) is high. Therefore, we could expect a comparable performance of both schemes in this region. In the high-SNR region, for an almost AWGN channel, we expect that both schemes should also deliver comparable performance (Fig. 14).

VI. CONCLUSION

The MH-iterative scheme is an iterative IN mitigation scheme for OFDM-based transmission which delivers good performance with low complexity in the receiver design. In this paper, we report two ideas to improve its performance. The first idea is to use the RN scheme as the preprocessing IN mitigation scheme instead of the CN scheme. The second idea is to use the output vector \( \hat{r} \) of the preprocessing IN mitigation scheme in all iterations instead of only in the zeroth iteration. The performance comparison in terms of the BER between the MH-iterative scheme and the proposed scheme is made with the help of simulations of uncoded QPSK-256OFDM transmission in the two-state IN channel model. The results show that the proposed scheme brings better performance than the MH-iterative scheme.

REFERENCES


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