Mitigating the Effect of Impulsive Noise in Power Line Communications with Preprocessing

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***Abstract*—This paper investigates preprocessing for mitigating the impulsive noise encountered in power line communications (PLC). In particular, we consider the scenario of using powerful polar codes in the presence of Middleton Class-A Noise (MCAN). Two preprocessing methods, including blanking and clipping, are investigated before the use of successive cancellation list (SCL) decoding. With a Markov chain modeling for MCAN, the blanking is demonstrated to be an effective method for discriminating the state of MCAN and it simply erases the channel when the corrupted state due to the presence of impulsive noise is detected. The use of blanking, along with the log-likelihood ratio computation, could achieve significant gain for SCL decoding of polar codes over PLC channels, which is validated by extensive experiments.**

***Index Terms*—Power-line commmunications, impulsive noise, polar codes, preprocessing.**

I. Introduction

POWER line communications (PLC) could provide cost-effective solutions to various smart grid applications [1], since no extra communication infrastructure is required for accessing the network service. However, one of the main challenge for PLC is the existence of impulsive noise [2], [3], which may severely degrade the performance of PLC.

Error-correcting codes are powerful tools for mitigating the effect of channel noise. Modern channel coding schemes, including low density parity check (LDPC) codes, turbo codes and polar codes have been evaluated over PLC channels and significant coding gains have been observed [5]–[10]. To further mitigate the impact of impulsive noise, various preprocessing [4], [5] methods have been extensively proposed. Currently, the use of preprocessing for mitigating the effect of impulsive noise is not well understood.

In this paper, the use of preprocessing for mitigating the effect of impulsive noise is investigated. With a Markov chain modeling of Middleton Class-A Noise (MCAN), the preprocessing method of blanking can be considered as a mechanism to identify the channel state and erase the channel whenever the impulsive noise is detected. Simulation results show that the use of blanking, along with the LLR computation, is very effective for SCL decoding of polar codes over PLC channels.

This work was supported by grant from the Nari Group Corporation (State Grid Electric Power Research Institute).

II. System Model

A. Polar Codes

An (N, K) polar code ($N = 2^n, n \geq 1$,$1 \leq K \leq N$) is a linear block code generated by

$$\mathbf{c} = \mathbf{u}F^{\otimes n}, \tag{1}$$

where $F = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$, $F^{\otimes n}$ denotes an n-th Kronecker power of F, and $\mathbf{u} = (u_1, \cdots, u_N)$ denote the uncoded bit sequence, including K information bits and $N - K$ frozen bits, which are determined by the channel polarization.

B. Channel Model

Consider that the polar coded bits are BPSK modulated, and further transmitted over an additive white Gaussian noise (AWGN) channel. Let $\mathbf{c} = (c_1, c_2, \cdots, c_N)$ denote a codeword of C. It is mapped to $\mathbf{x} = (x_1, x_2, \cdots, x_N)$ by $x_n = 2c_n - 1$ before transmission. At the receiver, we get the received vector $\mathbf{y} = (y_1, y_2, \cdots, y_N)$ with

$$y_k = x_k + z_k, k = 1, 2, \cdots, N \tag{2}$$

where z_k is often modeled as Middleton class-A noise in power line communications and $E[z_k] = 0, E[z_k^2] = \sigma_B^2 + \sigma_I^2 = (2R_cE_b/N_0)^{-1}$ with σ_B^2 denoting the variance of background AWGN noise, σ_I^2 denoting the variance of impulsive noise and R_c denoting the coding rate.

In general, PLC is characterized by the impulsive noise, which is sharply compared to the well-known additive white Gaussian noise (AWGN). In essence, it contains both background AWGN noise and impulsive noise, namely,

$$z_k = w_k^B + \sqrt{O_k}w_k^I, \tag{3}$$

where w_k^B is the zero-mean white background Gaussian noise with variance of σ_B^2, w_k^I is the zero-mean white Gaussian noise with variance of σ_I^2/A and O_k denotes a Poisson-distributed sequence with the pdf of $\Pr(O_k = m) = \frac{A^m}{m!}e^{-A}, m = 0, 1, \cdots$. Here, A denotes the impulsive index.

The probability density function (PDF) of z_k can be expressed as

$$p_Z(z) = \sum_{m=0}^{\infty} \exp(-A)\frac{A^m}{m!}\frac{1}{\sqrt{2\pi\sigma_m^2}}\exp\left(-\frac{z^2}{2\sigma_m^2}\right), \tag{4}$$

where

$$\sigma_m^2 = (\sigma_B^2 + \sigma_I^2)\frac{mA^{-1}+\Gamma}{1+\Gamma}, \tag{5}$$

and $\Gamma = \frac{\sigma_B^2}{\sigma_I^2}$, A denotes the impulsive index. Note that the impulsive index identifies the average number of impulses over the signal period.

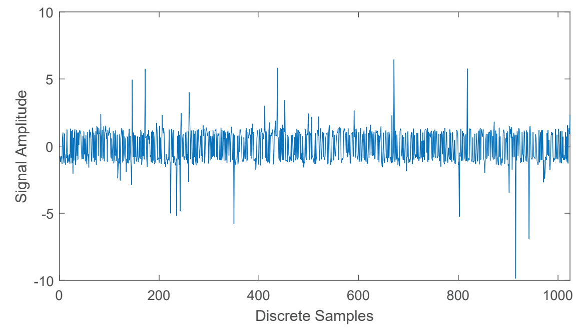

Fig. 1. Sample illustration of BPSK modulated signals over the MCAN channel ($E_b/N_0 = 2$ dB).

III. Preprocessing and LLR Computation in the Presence of Impulsive Noise

A. Markov Chain Modeling and Channel Capacity

In , the MCAN channel is modeled as a Markov chain. By assuming that both the transmitter and the receiver know the channel state, the channel capacity with binary inputs can be computed. Let the probability of taking the channel's m-th state (s_m) denoted by

$$\pi_m = P_r(S_t = s_m) = e^{-A}\frac{A^m}{m!}, m = 0, 1, \cdots. \tag{6}$$

The MACN channel capacity can be written as

$$C = \sum_{m=0}^{\infty} \pi_m C_m, \tag{7}$$

where

$$C_m = 1 - \frac{1}{\sqrt{2\pi\sigma_m^2}}\int_{-\infty}^{\infty} e^{-\frac{(y+1)^2}{2\sigma_m^2}} \log_2(1 + e^{\frac{2y}{\sigma_m^2}})dy. \tag{8}$$

For the setting of $A = 0.1, \Gamma = 0.1, E_b/N_0 = 2$ dB, we have that $C = 0.9154$,

$$\pi_0 = 0.9048, \pi_1 = 0.0905, \pi_2 = 0.0045, \pi_3 = 0.0002$$
$$C_0 = 0.9999, C_1 = 0.1148, C_2 = 0.0600, C_3 = 0.0406.$$

It is clear that $C_0 \approx C$. This means that the channel capacity of MCAN can be approximately achieved if we could discriminate between the state of no presence of impulsive noise $S_t = s_0$ and the state of the presence of impulsive noise $S_t \neq s_0$,

B. Detection of Channel State and Preprocessing

Give the received vector $\mathbf{y} = (y_1, y_2, \cdots, y_N)$, it is of importance to first detect the corresponding state sequence $\mathbf{S} = (S_1, S_2, \cdots, S_N)$ for better estimating the transmitted message. Essentially, the Maximum a Posteriori (MAP) estimation of S_k can be formulated as

$$\begin{aligned} S_k &= s_{m^*} \\ m^* &= \arg\max_m P\left(S_k = s_m|\mathbf{y}\right). \end{aligned} \tag{9}$$

As the MAP estimation is rather involved, two well-known preprocessing methods, including blanking and clipping, have developed an inherent practical approach for estimating the presence of impulsive noise, namely,

$$S_k = s_0 \quad \text{if} \quad y_k \leq Q, \tag{10}$$

where Q is a threshold to be determined in practice.

Although two methods employ the same mechanism for the detection of channel state, Blanking and clipping have their difference in the subsequent processing of the received samples. The blanking method simply sets the received sample to zero if the presence of impulsive noise is detected ($S_k \neq s_0$), namely,

$$\bar{y}_k = y_k\delta(|y_k| \leq Q), \tag{11}$$

while the clipping method set the received sample to the thresold value if $S_k \neq s_0$, namely,

$$\bar{y}_k = y_k\delta(|y_k| \leq Q) + Q\delta(|y_k| > Q). \tag{12}$$

From the viewpoint of approaching the capacity (7), the blanking method is preferable, which means that if the presence of impulsive noise is detected, the corresponding received samples are not reliable and should be erased.

C. Simple vs. Rigorous LLR Computation

Since preprocessing has the inherent capability of identifying the channel state, a simple log-likelihood ratio (LLR) computation is to employ the standard LLR computation for the AWGN channel, namely,

$$L_k = \log\frac{\Pr(c_k = 1|\bar{y}_k)}{\Pr(c_k = 0|\bar{y}_k)} = \frac{2}{\sigma_B^2}\bar{y}_k. \tag{13}$$

For the Middleton class-A channel, the rigorous channel LLR can be computed as

$$\begin{aligned} L_k &= \log\frac{\Pr(c_k = 1|y_k)}{\Pr(c_k = 0|y_k)} \\ &= \log\frac{\sum_{m=0}^{\infty}\frac{A^m}{m!}\frac{1}{\sqrt{2\pi\sigma_m^2}}\exp\left(-\frac{(y_k-1)^2}{2\sigma_m^2}\right)}{\sum_{m=0}^{\infty}\frac{A^m}{m!}\frac{1}{\sqrt{2\pi\sigma_m^2}}\exp\left(-\frac{(y_k+1)^2}{2\sigma_m^2}\right)}. \end{aligned} \tag{14}$$

Define

$$\gamma_m(|x|) = \ln\left(\frac{A^m}{m!}\frac{\sqrt{2\pi\sigma_0^2}}{\sqrt{2\pi\sigma_m^2}}\exp\left(-\frac{|x|^2}{2\sigma_m^2}\right)\right) = \ln\left(\frac{A^{m+1}\Gamma}{m!(m+A\Gamma)}\right) - \frac{|x|^2}{2\sigma_m^2}. \quad (15)$$

Then, the LLR can be written as

$$L_k = \ln\frac{\sum_{m=0}^{\infty} e^{\gamma_m(|x-1|)}}{\sum_{m=0}^{\infty} e^{\gamma_m(|x+1|)}} = \ln\left(\sum_{m=0}^{\infty} e^{\gamma_m(|x-1|)}\right) - \ln\left(\sum_{m=0}^{\infty} e^{\gamma_m(|x+1|)}\right) \quad (16)$$

By noting that

$$\log(e^a + e^b) = \max(a,b) + \log(1+e^{-|a-b|}) = \max(a,b) + f_c(|a-b|), \quad (17)$$

The LLR in (16) can be efficiently computed and in practice, 4 items ($m = 0,1,2,3$) are enough to compute the LLR in (16).

IV. Simulation Results

We consider the use of powerful polar codes over the PLC channel. With MCAN, we employ the setting of $A = 0.1, \Gamma = 0.1$. The rate-1/2 polar code of $(N = 1024, K = 512)$ of rate 0.5 is used. For decoding, we assume that the successive cancellation list (SCL) decoding with list size of $L \geq 1$ is performed.

For either blanking or clipping, the use of $Q = 1 + 3\sigma_B$ is employed, which is shown to be very effective in experiments.

A. Preprocessing vs. No Preprocessing

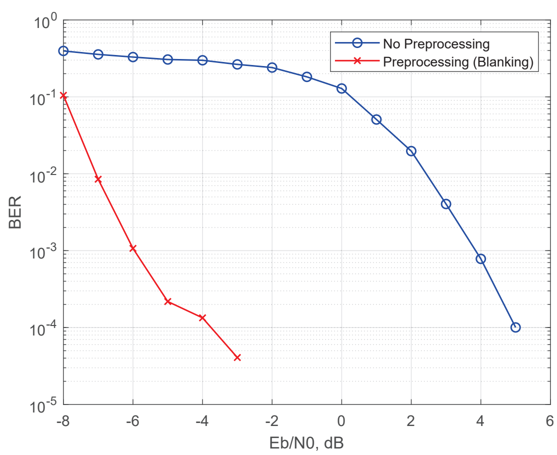

Fig. 2. BER performance of SCL decoding of polar codes with/without preprocessing.

Fig. 2 presents simulation results illustrating the SCL decoding ($L = 4$) performance in terms of bit-error rate (BER) with/without preprocessing. There is about 9 dB gap in the working E_b/N_0 at the bit-error-rate of $1e-4$ between

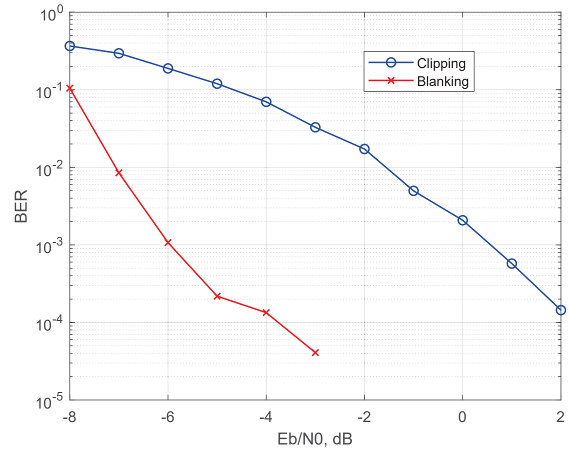

Fig. 3. Blanking vs. Clipping for SCL decoding of polar codes

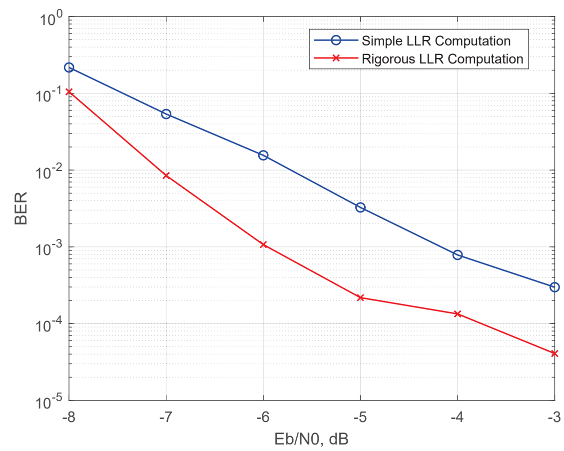

Fig. 4. Simple vs. Rigorous LLR computation for SCL decoding of polar codes with blanking.

preprocessing and no preprocessing. With blanking, the perfect erasing of the received samples in the presence of impulsive noise could help us to identify the AWGN channel in the state of s_0. The equivalent channel $(E_b/N_0)_{\text{eqiv}}$ at the state of s_0 is defined to be $(E_b/N_0)_{\text{eqiv}} = 1/(2R_c\sigma_B^2)$. With the working $E_b/N_0 = -4$ dB, the equivalent $(E_b/N_0)_{\text{eqiv}} = 3.72$ dB at the state of s_0. This may explain the big gap between preprocessing and no preprocessing.

B. Blanking vs. Clipping

Fig. 3 demonstrates the use of blanking vs clipping before the SCL decoding of polar codes with $L = 4$. Clearly, the use of clipping is undesirable since the clipped samples are still of significant energy, which, however, contains unreliable information for the transmitted message. Simulation results confirmed that clipped samples are harmful for the subsequent decoding of polar codes.

C. Simple vs. Rigorous LLR Computation

We also show the effect of simple vs. rigorous LLR computation on the decoding performance, along with blanking. As shown in Fig.4, the use of rigorous LLR computation results into improved BER performance.

V. Conclusion

With a Markov chain modeling for MCAN, this paper interprets the preprocessing method of blanking as an effective method for discriminating the state of MCAN. With blanking, the channel samples are simply erased if the corrupted state due to the presence of impulsive noise is detected. The use of blanking, along with the proposed log-likelihood ratio computation, could achieve significant gain for SCL decoding of polar codes over PLC channels. The preprocessing method of clipping is not recommended due to its doubtful mechanism in dealing with corrupted samples, which severely limits its performance.

Acknowledgment

This work was supported in part by the Science and Technology Project of State Grid Jiangsu Electric Power Co., Ltd under Grant J2021086 (Research on Key Technologies for Improving the Practical Level of HPLC Communication in Power Internet of Things).

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