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Research on Network Coding Algorithm in Two-way Relay Hybrid System of Wireless/Power Line

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In order to improve the performance of long-distance communication and fulfill the requirement of wireless-power line two-way relay hybrid system, a physical layer network coding algorithm based on the BP decoding and the threshold approximation of relay probability density function is proposed in this paper. By analyzing the probability density distribution of the relay signals,the initial logarithm likelihood ratio formulas of relay coding signals are deduced after physical layer network coding, and the BP decoding is carried out. Then the multidimensional signal is simplified by using the threshold method.The simulation results have verified the validity and reliability of the proposed algorithm as an optimized power distribution factor. Under the premise of decreasing complexity, the proposed algorithm can effectively ensure the performance requirements of wireless-power line two-way relay hybrid system.

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1.Introduction

It is necessary to establish a reliable, efficient two-way interaction and integration of communication network so as to achieve the power flow and information flow of organic integration in the smart grid [1]. At home, the majority devices use wireless communication technology to communicate with other terminals; on the other hand, the power lines can be used to communicate because of DC power supply. It is possible to joint WLC and PLC [2]. As the PLC technology is widely used at smart home, the study on hybrid communication method based on WLC and PLC is of some practical significance [3].

The collaborative relaying technology firstly utilizes relay nodes to receive information processing and then transfers the signal to the destination node to improve the reliability of long-distance communication. The collaborative relay algorithm mainly includes amplification and forwarding (AF), decoding forwarding (DF) and estimation forwarding (EF), etc. Researches mostly concerned about the system performance [4] and the energy efficiency [5]. Aiming at the power line channel, The AF was used to improve the energy efficiency of the collaborative power line communication relay system [6]. The physical layer security of the collaborative relay system under the power line communication was improved by deriving the mathematical expression of the average security capacity [7].However, the above-mentioned power line relay technology only dealt with simple relay algorithms such as AF and DF, and the scene of one-way relay communication while not considering the requirements of two-way communication in the smart grid.

The physical layer network coding (PLNC) can overcome half-duplex limitations, improve the system frequency efficiency, throughput and gain diversity for bidirectional communication and multi-user collaboration scenarios. The wireless collaborative relay PLNC under the three-time slot was studied in detail[8-10]. The performance was better than the traditional PLNC algorithm based on AF and DF protocol. However, as the PLNC algorithms in the above research only aimed at the Gaussian white noise in wireless communication, it cannot be applied to PLC with impulsive noise characteristics; thus it is necessary to carry out researches on the parameters of multidimensional impulse noise.

Compared with the three-time slot PLNC algorithm [8-10], the channel utilization ratio of the two-time slot PLNC was higher. The application of PLNC in power line communication was studied and then the system performance under AF algorithm was deduced, but it failed to analyze the influence of impulse noise on coding algorithm[11]. Research on multidimensional noise estimation and joint signal processing for two-time slot PLNC algorithm is in its infancy.

In various noises of low-voltage power line channel, the impulse noise is the main factor that affects the high-speed power line communication and the complicated channel coding technique must be considered.At present, the low density Parity code (LDPC) is closest to Shannon limit [12]. On this basis, this paper deduces a PLNC-LDPC algorithm based on BP decoding and threshold approximation.

2. System Model and Information Processing

Fig. 1 is a two-way wireless-power line collaborative relay system model, Where A with B is a stand-alone source node and R represents the relay node. Assuming that all nodes are in half-duplex mode, the receiver uses ideal channel estimation algorithm to obtain the channel parameter information. The relay system adopts the two-time slot information interaction protocol.

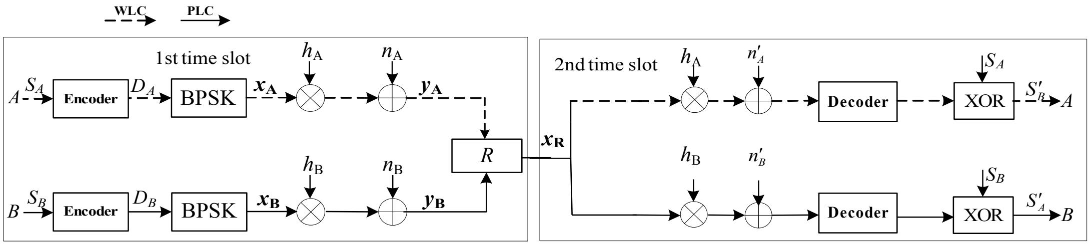


Figure 1: System Model

The 1st time slot: the original information is encoded and modulated by the source nodes A and B, which send information to relay R simultaneously.h_{IR}represents the channel fading coefficient, where $\mathrm{I} \in \{\mathrm{A}, \mathrm{B}\}$. P_{I} denotes the transmitting power and_n_{IR} indicates the channel noise. Noise n_{AR} satisfies normal distribution with the mean is 0 and the variance is σ_A^2 in the wireless channel. Noise n_{BR} meets a class A of noise model in the power line channel, and the probability density function of the noise amplitude Z is

$$p_B(z) = \sum_{i=0}^{\infty} \frac{e^{-A} A^i}{i!} \cdot \frac{1}{\sqrt{2\pi\sigma_{\mathrm{i}}^2}} \exp\left(-\frac{z^2}{2\sigma_{\mathrm{i}}^2}\right) \tag{2.1}$$

Where A indicates the pulse exponent, the greater the A is, the closer the noise statistical characteristics will be to the gauss characteristics; the smaller the A is , the stronger the non Gauss trend will be, that is, the stronger the impact will be. The variances σ_i^2 can be written as $\sigma_i^2 = \left(1 + \frac{i}{A\Gamma}\right)\sigma_0^2$, where σ_0^2 represents the background Gaussian noise, while Γ is a positive parameter describing the power of the impulse noise. Namely, the total noise Power is $\sigma_B^2 = \sigma_0^2\left(1 + \frac{1}{\Gamma}\right)$.The information received by the relay node R is

$$y = h_{AR}\sqrt{P_A}x_A + h_{BR}\sqrt{P_B}x_B + n_{AR} + n_{BR} \tag{2.2}$$

Without loss of generality, assume that the signal-to-noise(SNR) ratio of the channels on both sides of the relay is equal, that is

$$\sigma_A^2 = \sigma_B^2 \tag{2.3}$$

If the relay adopts AF, the relay forwarding signal is

$$x_{R,AF} = y / g \tag{2.4}$$

g is normalized factor, which has the following form

$$g = \sqrt{h_{AR}^2 P_A + h_{BR}^2 P_B + \sigma_A^2 + \sigma_B^2} \tag{2.5}$$

If PLNC is adopted, the relay utilizes $S_R = S_A \oplus S_B$ ($\oplus$ is XOR) to the signal processing, corresponding to the modulated information is

$$x_R = x_A \cdot x_B \tag{2.6}$$

The following mapping relationships in Table 1 can be fulfilled.

After the relay receives the information, it firstly carries on the PLNC, then adopts the BP decoding. The BP decoding algorithm can be described by the information iteration under LLR.

The initialization formula is

$$\Lambda = \log\left(\frac{p_r(x_R = +1 \mid y)}{p_r(x_R = -1 \mid y)}\right) = \log\left(\frac{p_r\left(y - h_{AR}\sqrt{P_A} - h_{BR}\sqrt{P_B}\right) + p_r\left(y + h_{AR}\sqrt{P_A} + h_{BR}\sqrt{P_B}\right)}{p_r\left(y - h_{AR}\sqrt{P_A} + h_{BR}\sqrt{P_B}\right) + p_r\left(y + h_{AR}\sqrt{P_A} - h_{BR}\sqrt{P_B}\right)}\right) \tag{2.7}$$

x_A	x_B	x_R
+1	+1	+1
+1	-1	-1
-1	+1	-1
-1	-1	1

Table 1: Bit-XOR Truth Table

The 2nd time slot: the relay sends back the signal obtained by relay processing to the source nodes A and B decoding. Assume that all channels and noise power are symmetrical in one transmission cycle. On the receiving end, there are:

$$y_{RI} = h_{RI}\sqrt{P_R}\,x_R + n_{RI} \tag{2.8}$$

With A-end, for example, when the message y_{RA} is sent back to A-end by the relay. The y_{RA} of BP decoding, get S_{RA}, and then XOR itself A side information, can decode at this time to get S_B. B-end similarly decodes the S_A.

3. PDF Analysis of Relay Information

According to the noise to satisfy the Gaussian distribution added in the form, as defined:

$$r(x_A, x_B) = y - h_{AR}\sqrt{P_A}\,x_A - h_{BR}\sqrt{P_B}\,x_B = n_{AR} + n_{BR} \tag{3.1}$$

The PDF of r can be obtained

$$p_r(r(x_A, x_B)) = \sum_{i=0}^{\infty} \frac{e^{-A}A^i}{i!} \cdot \frac{1}{\sqrt{2\pi\left(\sigma_{\mathrm{A}}^2 + \sigma_{\mathrm{i}}^2\right)}} \exp\left(-\frac{\left|r(x_A, x_B)\right|^2}{2\left(\sigma_{\mathrm{A}}^2 + \sigma_{\mathrm{i}}^2\right)}\right) \tag{3.2}$$

As the PDF of Class A noise model contains infinite summation computation, it is necessary to make simplification. In general, pulse exponent A is less than 0.2, A^i/i is already very small when i more than 1. For example, when A = 0.2, i = 2, $A^i/i!$ =0.02. So i takes 0 and 1, (3.2) can be simplified to take the first two forms:

$$p_r(r(x_A, x_B)) = \frac{\exp(\text{-A})}{\sqrt{2\pi\left(\sigma_{\mathrm{A}}^2 + \sigma_0^2\right)}} \exp\left(-\frac{\left|r(x_A, x_B)\right|^2}{2\left(\sigma_{\mathrm{A}}^2 + \sigma_0^2\right)}\right) + \frac{\mathrm{A}\cdot\exp(\text{-A})}{\sqrt{2\pi\left(\sigma_{\mathrm{A}}^2 + \sigma_1^2\right)}} \exp\left(-\frac{\left|r(x_A, x_B)\right|^2}{2\left(\sigma_{\mathrm{A}}^2 + \sigma_1^2\right)}\right) \tag{3.3}$$

Where

$$\sigma_A^2 = \sigma_B^2 = \sigma_0^2\left(1 + \frac{1}{\Gamma}\right), \quad \sigma_1^2 = \sigma_0^2\left(1 + \frac{1}{A\Gamma}\right)$$

which represent only the background noise and Gaussian noise in the channel

$$p_{Back}(r(x_A, x_B)) = \frac{\exp(\text{-A})}{\sqrt{2\pi\left(\sigma_{\mathrm{A}}^2 + \sigma_0^2\right)}} \exp\left(-\frac{\left|r(x_A, x_B)\right|^2}{2\left(\sigma_{\mathrm{A}}^2 + \sigma_0^2\right)}\right) \tag{3.4}$$

Since the calculation of (2.7) is necessitated for the summing and logarithm calculation of (3.3), the computation of the polynomial and the logarithm is very complex. Thus it is necessary to simplify the formula and the operation. The simplification is mainly for the $p(r(x_A, x_B))$ in Formula (3.3).

4. Threshold Approximation Simplification Method

The values of two items in (3.3) are relatively small. To simplify the computation, order

$$p_r(r(x_A,x_B)) = \max\left(\frac{\exp(\text{-A})}{\sqrt{2\pi\left(2+\frac{1}{\Gamma}\right)}\sigma_0}\exp\left(-\frac{\left|r(x_A,x_B)\right|^2}{2\left(\sigma_{\text{A}}^2+\sigma_0^2\right)}\right),\frac{\text{A}\cdot\exp(\text{-A})}{\sqrt{2\pi\left(2+\frac{1}{\Gamma}+\frac{1}{A\Gamma}\right)}\sigma_0}\exp\left(-\frac{\left|r(x_A,x_B)\right|^2}{2\left(\sigma_{\text{A}}^2+\sigma_1^2\right)}\right)\right) \quad (4.1)$$

Because of the computation of LLR in (2.7), $\exp(-A)/\sqrt{2\pi}\sigma_0$ will be eliminated, so directly compare

$$a(r(x_A,x_B)) = \frac{1}{\sqrt{\left(2+\frac{1}{\Gamma}\right)}}\exp\left(-\frac{\left|r(x_A,x_B)\right|^2}{2\left(\sigma_{\text{A}}^2+\sigma_0^2\right)}\right) \quad b(r(x_A,x_B)) = \frac{\text{A}}{\sqrt{\left(2+\frac{1}{\Gamma}+\frac{1}{A\Gamma}\right)}}\exp\left(-\frac{\left|r(x_A,x_B)\right|^2}{2\left(\sigma_{\text{A}}^2+\sigma_1^2\right)}\right)$$

The observations find that the variation of $b(r(x_A,x_B))$ with $\left|r(x_A,x_B)\right|^2$ is very small and close to a constant. With $\left|r(x_A,x_B)\right|^2$ as variable, make $a(r(x_A,x_B)) = b(r(x_A,x_B))$, at this time, the collation can be written as:

$$\frac{1}{\sqrt{\left(2+\frac{1}{\Gamma}\right)}}\exp\left(-\frac{\left|r(x_A,x_B)\right|^2}{2\left(\sigma_{\text{A}}^2+\sigma_0^2\right)}\right) = \frac{1}{\sqrt{\left(2+\frac{1}{\Gamma}\right)}}\left(A\sqrt{\frac{2+\frac{1}{\Gamma}}{2+\frac{1}{\Gamma}+\frac{1}{A\Gamma}}}\right)^{A\Gamma\left(2+\frac{1}{\Gamma}+\frac{1}{A\Gamma}\right)} = \Delta \quad (4.2)$$

That is, $p(r(x_A,x_B))$ can be approximately equal to a constant when $r(x_A,x_B)$ takes a certain value

$$p_r(r(x_A,x_B)) = \frac{\exp(-A)}{\sqrt{2\pi}\sigma_0}\max\left(a(r(x_A,x_B)),\Delta\right) \quad (4.3)$$

Substitute (2.7), thus:

$$\begin{aligned}\Lambda &= \log\left(\frac{p_r\left(r(+1,+1)\right)+p_r\left(r(-1,-1)\right)}{p_r\left(r(+1,-1)\right)+p_r\left(r(-1,+1)\right)}\right)\\ &= \log\left(\frac{\max\left(a(r(+1,+1)),\Delta\right)+\max\left(a(r(-1,-1)),\Delta\right)}{\max\left(a(r(+1,-1)),\Delta\right)+\max\left(a(r(-1,+1)),\Delta\right)}\right)\end{aligned} \quad (4.4)$$

At this time, the solution is much simpler than (2.7),and Δ is fixed with nothing to do with $r(x_A, x_B)$ and y but A and Γ. In the actual situation, as long as the two parameters are known, Δ can be obtained with fixed value and high robustness. However, as the use of threshold approximation method has subtle errors with the original (3.3) type of $p_r(r(x_A,x_B))$, it makes the error in the calculation of initialization LLR in BP decoding, and the BER is slightly worse than the original algorithm.

5. Simulation Analysis

This section mainly carries on the simulation experiment in respect of several algorithms. If there is no special description, the total power of the system is 3, $P_A=P_B=P_R=1$. h_{AR} and h_{RA} in WLC satisfy the Rayleigh distribution, and the fading energy is normalized. h_{BR} and h_{RB} in WLC satisfy logarithmic normal distribution. Assume that each source employs LDPC code defined in IEEE 802.11 (the packet length is 1296 information bits) and iteration number of decoding is 50.

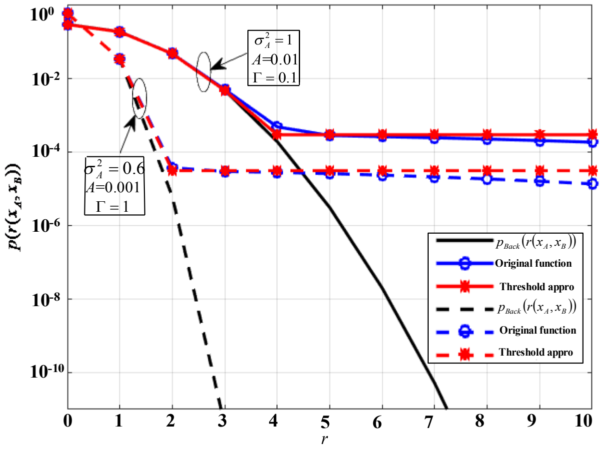
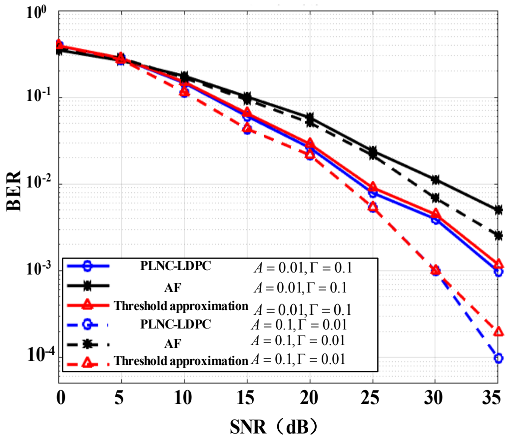


Figure 2: Comparison of the Approximate Method with the Original of $p_r(r(x_A, x_B))$

In order to analyze the validity of the threshold approximation, for different noise parameters of class-A model,make comparison of $p_r(r(x_A,x_B))$ in three formulas (3.3), (3.4) and (4.3) in Fig 2. When $r(x_A,x_B)$ is less than 2, the $p_r(r(x_A,x_B))$ of the simplified computation in (4.3) is consistent with the original $p_r(r(x_A,x_B))$ and $p_{Back}(r(x_A,x_B))$ curves. When $r(x_A,x_B)$ is greater than 2, the gap between the threshold approximation (4.3) and the $p_{Back}(r(x_A,x_B))$ is gradually apparent, but it is still well aligned with the original $p_r(r(x_A,x_B))$; therefore, the threshold approximation method presented in this paper highlights good accuracy; besides, it can effectively guarantee the performance of BP decoding of relay nodes while decreasing the computational complexity.



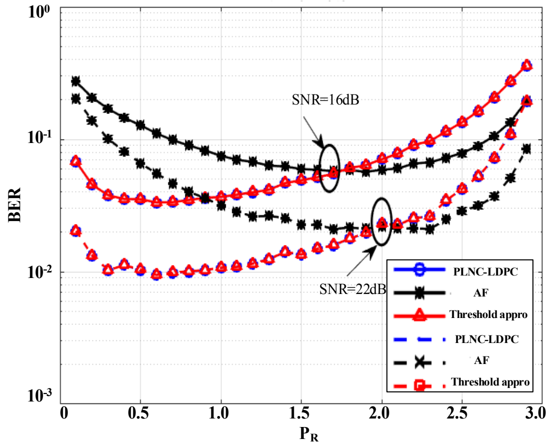


Figure 3: Bit Error Rate Comparison

Figure 4: Comparison of the Power Allocation

Fig. 3 compares the Bit error rate (BER) of the AF, the original and threshold PLNC algorithms. The performance of the original and threshold algorithm is significantly better than the AF algorithm in high SNR (SNR>10dB). In addition, the curves of the threshold algorithm are fairly close to the original algorithm, only when the 1~2dB gap exists in SNR>30dB. So it is reasonable to simplify the original formula by using the threshold approximation method. In summary, while preserving the performance of the original algorithm, the threshold algorithm simplifies the computational complexity, and has advantages in PLNC algorithms. In addition, the very small performance loss is caused by using the threshold approximation method, which makes error in the initialization LLR in BP decoding .

6. Conclusion

In order to improve the performance of relay system, the collaborative technology of relay physical layer has been widely concerned. In this paper, a threshold approximate PLNC-LDPC algorithm based on PDF is proposed for the two-way relay of wireless-power line. The performance of this algorithm with AF and the original PLNC-LDPC algorithm is compared by simulation. It has been proved that this algorithm can reduce the complexity of operation greatly while guaranteeing the performance, and it is an optimum power allocation factor to minimize BER.

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