International Journal of u- and e- Service, Science and Technology
Vol.9, No. 5 (2016), pp.181-188
http://dx.doi.org/10.14257/ijunesst.2016.9.5.16

Precoding Method for Broadband PLC MIMO System of Eliminating Interference

Jingxue Ran[1] and Yufei Cao[2]

[1]Centre of Data, MinZu University of China, Beijing, 100081, China
[2]Information engineering college, MinZu University of China, Beijing, 100081, China
[1]ranjingxue@vip.163.com, [2]cyf1058@163.com

Abstract

Power line carrier communication, with the widespread application, broadband multi-input multi-output system will have a co-channel interference, the interference is in addition to asynchronous pulse noise and pulse cycle factors influencing the multi-input multi-output (MIMO) system's largest broadband power line carrier. Aiming at this problem, this paper, by using multiple input multiple output channel state information, the sender with the method of block diagonalization, eliminate the interference between the channel, so as to improve the capacity of broadband power line carrier system, at the same time reduce the bit error rate of the system. Through the simulation results and analysis can show that the proposed block diagonalization pre-coding method effectively eliminates the common channel interference, improve the drying ratio, thus improve the maximum mutual information of the system and reduce the bit error performance of the system.

Keywords: *PLC; Block Diagonalization; Precoding; Interference Elimination*

1. Introduction

Power line communication (PLC) transmit information via existing power cable. PLC's biggest advantage is that it can communicate without needing to add other lines of laying. PLC communication scenario began to apply in low rate, after decades of development, especially the orthogonal frequency division multiplexing applying in the PLC, making the PLC into the broadband power line carrier communication era. In the indoor power line, there are three transmission lines: 1) phase line 2) neutral line 3) protective earth line. The traditional PLC work on single-input single-output (SISO) systems, i.e., to work on both truth and neutral wires. One as the transmission lines, other one as receiving lines. However, it can work in a multiple-input multiple-output (MIMO) system, making it possible to increase the capacity of the system and change the stability of the system .It is proved that using MIMO technology, the capacity of PLC system is improved [3-5]. To take full advantage of MIMO technology , we must study the characteristics of the channel and interference suppression technology, because Co-Channel Interference (CCI) not only reduces the capacity of the system , but also reduces the signal to noise ratio (SNR)of the received, so the bit error rate (BER) increases, and affects the communication quality of PLC. The traditional method is used a balanced approach at the receiving end, such as maximal ratio combining or proportional consolidation method, these equilibrium method can eliminate the CCI, but due to the receive-side processing power is limited, and it will increase the power of transmitters. To solve this problem, this paper presents a block diagonalization precoding method which can eliminate interference between the power lines, thereby improving the performance of system.

ISSN: 2005-4246 IJUNESST

2. System Model

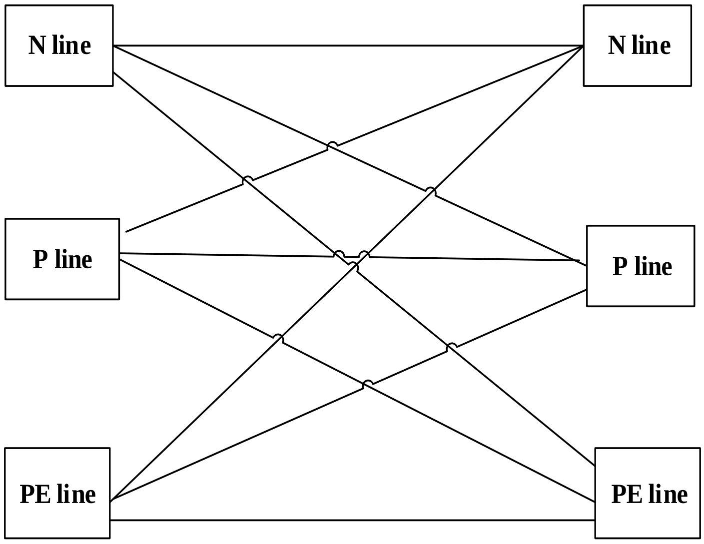

Figure 1. 3 * 3 Indoor MIMO Power Line Communication Channel

The model in this paper, similar to [2], with a transmitter and a receiver, the channel can be represented as $\mathbf{H}(f)$, and its matrix

$$\mathbf{H}(f) = \begin{bmatrix} h_{1,1}(f) & h_{1,2}(f) & \cdots & h_{1,M}(f) \\ h_{2,1}(f) & h_{2,2}(f) & \cdots & h_{2,M}(f) \\ \vdots & \vdots & \ddots & \vdots \\ h_{N,1}(f) & h_{N,1}(f) & \cdots & h_{N,M}(f) \end{bmatrix} \quad (1)$$

Where $h_{n,m}(f)$ represents the complex channel transfer matrix of the m-th transmitting end to the n-th receiving terminal, and the frequency is f. When $m = n$, transmitting channel $h_{n,m}(f)$ represents co-channel, when $m \neq n$, transmitting channel represents mutual interference channel. Assuming the sending signal of j-th sender as x_j, while the receiving noise of i-th receive as n_i. We can get the signal received by i-th receiving terminal is expressed as

$$y_i = \sum_{j=1}^{M} h_{i,j} x_j + n_i \quad (2)$$

Where y_i is the receiving the signal of i-th receiver. In order to simplify the model, the channel can be modeled as additive Gaussian white noise plus additive impulse noise, it can be expressed as

$$n_i = n_{awgn,i} + n_{ain,i} \quad (3)$$

All signals received by the receiver can be written in a matrix as

$$\begin{bmatrix} y_1 \\ \vdots \\ y_N \end{bmatrix} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,M} \\ \vdots & \ddots & \vdots \\ h_{N,1} & \cdots & h_{N,M} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_M \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_M \end{bmatrix} \quad (4)$$

It can also be abbreviated as

$$\mathbf{y} = \mathbf{Hx} + \mathbf{N} = \mathbf{Hx} + \mathbf{N}_{AWGN} + \mathbf{N}_{AIN} \tag{5}$$

$\mathbf{y}$ is a $N \times 1$ column vector of receiver, $\mathbf{H}$ is $N \times M$ channel transfer matrix, $\mathbf{x}$ is $M \times 1$ send vector, $\mathbf{N}$ as $N \times 1$ receiving end noise vector. $\mathbf{N}_{AWGN}$ Represents AWGN received noise, $\mathbf{N}_{AIN}$ represents additive impulse interference noise. Average channel gain $G = 1/B \int_0^B \left|\mathbf{H}(f)\right|^2 df$ can be approximated as a log normal distribution. For MIMO power line communication system, its capacity can be expressed as

$$C_{MIMO} = BE\left\{\log_2[\det\left(\mathbf{I} + \frac{s}{M}\mathbf{HH}^H\right)]\right\} \tag{6}$$

Where $E\{\bullet\}$ represents the average operation, unit matrix is $\mathbf{I}$, bandwidth is B, the average signal to noise ratio of per bit s, the conjugate transpose operations denoted by $(\bullet)^H$.

In addition, except the additive white Gaussian noise, there will be sharp and impulsive noise in the line communication system, its probability density function is

$$p_X(x) = \sum_{m=0}^{\infty} \frac{e^{-A}A^m}{m!\sqrt{2\pi\sigma_m^2}} \exp\left(-\frac{x^2}{2\sigma_m^2}\right) \tag{7}$$

Where A is a type of impulse noise, such as the plot of the unit time average number of pulses. σ_m^2 is the noise variance, which is defined as:

$$\sigma_m^2 = \left(\sigma_G^2 + \sigma_I^2\right)\frac{m/A + T}{1 + T} \tag{8}$$

Where σ_G^2 and σ_I^2 is the variance of the Gaussian noise and impulse noise, respectively, and $T = \sigma_G^2/\sigma_I^2$ is the Gaussian noise and impulse noise ratio.

3. Based on the Block Diagonalization Precoding Method

This section is to design block diagonal precoding, this algorithm considers using precoding matrix to send a signal at the transmitter, then the receiving signal as

$$\mathbf{y} = \mathbf{HTx} + \mathbf{N} \tag{9}$$

Where $\mathbf{T} \in \mathbb{C}^{N \times M}$ is the precoding matrix, so the restrictions need to be considered, namely the number of transmit branch equal to the receive branch. The mathematical expression is

$$M = \sum_{j=1}^{n} n_j \tag{10}$$

According to the joint processing scheme, the data at receiving end were as follows:

$$\hat{\mathbf{x}} = \mathbf{R}(\mathbf{HTx} + \mathbf{N}) \tag{11}$$

Where $\hat{\mathbf{x}}$ is $M \times 1$ receive data vector and the receiving end for balanced matrix is $\mathbf{R} \in \mathbb{C}^{M \times N}$. This section in order to get the optimal the sender matrix $\mathbf{T}$, the interference to other receivers is zero, considering the matrix decomposes into $\left[\mathbf{t}_1^T, \mathbf{t}_2^T, \cdots, \mathbf{t}_N^T\right]^T$,and assuming the receiving end received matrix $\mathbf{R}$ is conjugate symmetric matrix ,i.e., $\mathbf{RR}^H = \mathbf{I}$. In order to eliminate the co-channel interference between the receiving ends, it must meet the following conditions:

$$\mathbf{H}_i \mathbf{t}_j = 0 \quad i \neq j \tag{12}$$

If $N = 1$, this method can be achieve by using the pseudo inverse matrix of the channel. And complete diagonalization can also be applied in the case of $n = 1$, the receiver can be simplified, which the cost of reducing throughput, or increasing the transmission power for the price. The proposed algorithm in order to maximize the mutual information system, and the total transmission power is limited, block diagonalization throughput can be achieved.

$$C = \max_{\mathbf{R}, \mathbf{H}_j \mathbf{t}_j = 0} \log_2 \left| \mathbf{I} + \frac{1}{\sigma_n^2} \mathbf{H} \mathbf{T} \mathbf{H}^H \mathbf{T}^H \right| \tag{13}$$

According to their statistical properties, an expression can be obtained by (13) is:

$$C = \max_{\mathbf{R}, \mathbf{H}_j \mathbf{t}_j = 0} \sum_{j=1}^{N} \log_2 \left| \mathbf{I} + \frac{1}{\sigma_n^2} \mathbf{H}_j \mathbf{t}_j \mathbf{H}_j^H \mathbf{t}_j^H \right| \leq C_S \tag{14}$$

Define

$$\hat{\mathbf{H}}_j = \left[\mathbf{H}_1^T \cdots \mathbf{H}_{j-1}^T \mathbf{H}_{j+1}^T \cdots \mathbf{H}_K^T \right]^T \tag{15}$$

Zero interference constraints make $\mathbf{t}_j$ in the null space of $\hat{\mathbf{H}}_j$. This definition allows all the receiver can comply with zero interference. Data transmitted to the receiving end j, if $rank\left(\hat{\mathbf{H}}_j\right) < M$, it is possible to satisfy the condition of zero interference. Therefore, for any $\mathbf{H}_j$, block diagonalization precoding conditions

$$M > \max\left\{ rank\left(\hat{\mathbf{H}}_1\right) \cdots rank\left(\hat{\mathbf{H}}_K\right) \right\} \tag{16}$$

If the dimension meets all the conditions of the receiver, then the eigenvalue decomposition (SVD) of $\hat{\mathbf{H}}_j$, we can obtain

$$\hat{\mathbf{H}}_j = \tilde{\mathbf{U}}_j \tilde{\Xi} \left[\tilde{\mathbf{V}}_j^{(1)} \tilde{\mathbf{V}}_j^{(0)} \right]^H \tag{17}$$

Where $\tilde{\mathbf{v}}_j^{(1)}$ is the top L_j right singular vectors, and $\tilde{\mathbf{v}}_j^{(0)}$ is the last $\left(M - L_j\right)$ right singular vectors. As a result, $\tilde{\mathbf{v}}_j^{(0)}$ is the null space orthogonal basis of $\hat{\mathbf{H}}_j$, if independence conditions are met, you can define in formula (18)

$$\mathbf{H}' = \begin{bmatrix} \mathbf{H}_1 \tilde{\mathbf{V}}_1^{(0)} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \mathbf{H}_N \tilde{\mathbf{V}}_N^{(0)} \end{bmatrix} \tag{18}$$

The SVD of $\mathbf{H}_j \tilde{\mathbf{v}}_j^{(0)}$, we can obtain:

$$\mathbf{H}_j \tilde{\mathbf{V}}_j^{(0)} = \mathbf{U}_j \begin{bmatrix} \Xi & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{V}_j^{(1)} & \mathbf{V}_j^{(0)} \end{bmatrix}^H \tag{19}$$

And the final precoding matrix is

$$\mathbf{T} = \left[\tilde{\mathbf{V}}_1^{(0)} \mathbf{V}_1^{(1)} \; \tilde{\mathbf{V}}_2^{(0)} \mathbf{V}_2^{(1)} \cdots \; \tilde{\mathbf{V}}_N^{(0)} \mathbf{V}_N^{(1)} \right] \mathbf{\Delta}^{1/2} \tag{20}$$

According to the above imaginary numbers, limited conditions of the total power P, with optimal power allocation algorithm, *i.e.*, power water-filling algorithm, precoding method of block diagonalization can be summarized into the following processes:

1) For $j = 1,\cdots, K$

Using (17) calculates $\tilde{\mathbf{V}}_j^{(0)}$, *i.e.*, the right null space of $\hat{\mathbf{H}}_j$.

Computing SVD decomposition (using the (19))

$$\mathbf{H}_j \tilde{\mathbf{V}}_j^{(0)} = \mathbf{U}_j \begin{bmatrix} \Xi & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{V}_j^{(1)} & \mathbf{V}_j^{(0)} \end{bmatrix}^H$$

2) Under the limited conditions of the total power P, using the power water-filling algorithm calculates optimal matrix $\mathbf{\Delta}$.

3) Setting the precoding

$$\mathbf{T} = \begin{bmatrix} \tilde{\mathbf{V}}_1^{(0)} \mathbf{V}_1^{(1)} & \tilde{\mathbf{V}}_2^{(0)} \mathbf{V}_2^{(1)} \cdots & \tilde{\mathbf{V}}_N^{(0)} \mathbf{V}_N^{(1)} \end{bmatrix} \mathbf{\Delta}^{1/2} .$$

4. Simulation Result

In this section, compared of the performance of the proposed scheme and the other three schemes:

1. We do not use signal processing methods to eliminate the pulse interference, in Figure.2 and Figure 3 are recorded as "the noise that not eliminating pulse interference" [8];

2. Traditional means of using nonlinear processing, the method that through an iterative approach eliminating pulse interference, in Figure 2 and Figure 3 are credited as "traditional nonlinear methods" [9];

3. Using the traditional linear approach, i.e., using equilibrium model approach at the receiving end, in Figure 2 and Figure 3 as noted "traditional linear approach" [10].

In simulation, according to simulation defines of [10], we simulate the errors bit performance curves of three existing program and the proposed method, which the modulation uses QPSK, Fast Fourier Transform uses 128 bit, channel coding uses the convolution code that code rate is $1/2$, data bit for 72 bit, non-data bit for 56 bit, from Figure 2, we can see, as the transmission power increases, the BER decreases, errors bit performance as 10^{-3}, compared to the traditional nonlinear program ,this paper proposed program improves 2dB.

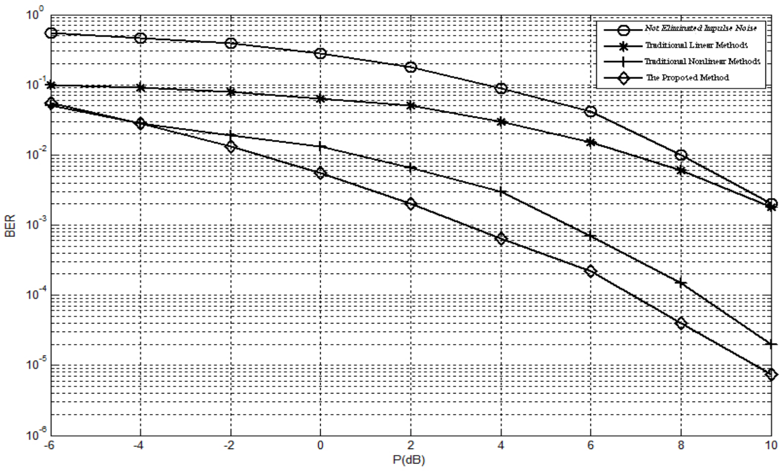

Figure 2. BER Comparison of Four Scenarios

Figure 3 is the modulation using 16-QAM, Fast Fourier transform uses 128 bit, channel coding uses the convolution code that code rate is $1/2$, data bit for 72 bit, non-data bit for 56 bit, with the increase of transmission power, the curve figure of the error bit performance. As can be seen from Figure 3, with the increase of the average SNR, the other three programs are in decline, in the BER performance for 10^{-3} , compared to conventional non-linear program, the proposed scheme has gain is 12dB. By comparing Figure 2 and 3, we can see that when the modulation order is small, it will bring a large gain.

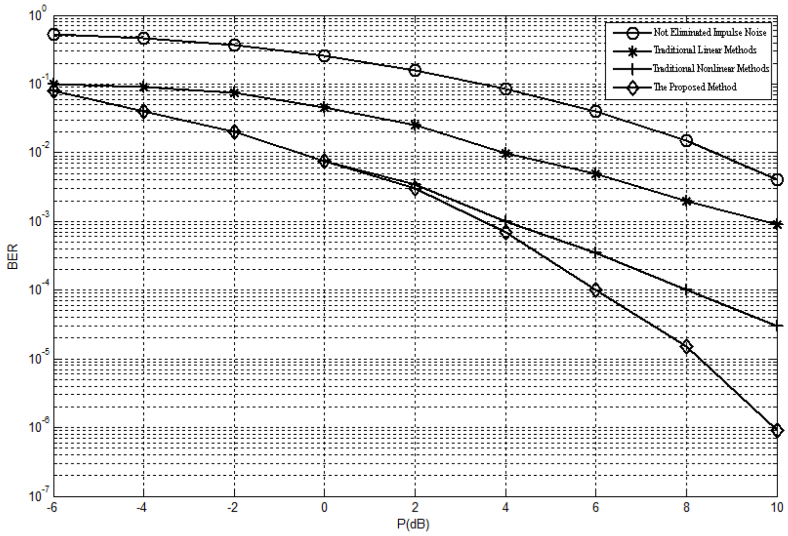

Figure 3. Error Rates Comparison of Four Scenarios

5. Conclusion

In this paper, aiming at the problem of multiple co-channel interference at the receiving end, we put forward different receiver zero interference block diagonalization precoding method, from the simulation results, compared with the other three schemes, the maximum mutual information and bit error performance of this method has a larger advantage. Of course, the article does not consider the situation that the channel state information is imperfect, we can improve in the next research.

References

[1] L. Su, J-H Zhang, L. Wang and Z-P. Wu, "Study on some key problems and technique related to microgrid", Power system protection and control, vol. 38, no. 19, **(2010)**, pp. 235-239.

[2] F. Wang, C. Zhang, C. He and Z.-G. Chen, "A scheme of online communication message analysis for protection relay fault information system", Power system protection and control, vol. 41. no. 05, **(2013)**, pp. 151-155.

[3] P. Yu, Y. J. Xue and B. G. Dong, "Prediction and analysis of the path loss in temporary communication system of substation based on Mesh network", Power system protection and control, vol. 41, no. 06, **(2013)**, pp. 117-122.

[4] Y. Yanjun, C. Feng, O. Jing and G. Hongwei, "Position Sensorless Control of IPMSM Based on Rotating High Frequency Signal Method", Transactions of china electronical society, vol. 28, no. 7, **(2013)**, pp. 26-31.

[5] W. Shenghua, Z. Yanping, L. Xiangdong and Q. Jianzhou, "Improvement of Control Strategy for Matrix Sinusoidal Converter with High Frequency Link", Transactions of china electronical society, vol. 28, no. 3, **(2013)**, pp. 228-233.

[6] S. Mingsong, H. Songling and Z. Wei, "Modeling and Analysis of Electrodeless Lamp System", Transactions of china electronical society, vol. 28, no. 4, **(2013)**, pp. 13-19.

[7] M. Nassar, A. Dabak, I. Kim, T. Pande and B. L. Evans, "Cyclostationary noise modeling in narrowband powerline communication for smart grid applications", Proc.IEEE Int.Conf. on Acoustics,Speech and Sig.Proc., **(2012)**, pp. 3089-3092.
[8] K. F. Nieman, J. Lin, M. Nassar, K. Waheed and B. L. Evans,"Cyclic spectral analysis of power line noise in the 3-200 kHz band", Proc.IEEE Int.Symp.power Line Comm.and Appl.,**(2013)**.
[9] M. Nassar, J. Lin, Y. Mortazavi, A. Dabak, I. H. Kim and B. L.Evans,"Local utility power line communications in the 3-500 kHz band:Channel impairments,noise,and standards", IEEE Sig.Proc.Mag.
[10] A. Al-Dweik, A. Hazmi, B. Sharif and C. Tsimenidis, "Efficient interleaving technique for OFDM system over impulsive noise channels", Proc. IEEE Int.Symp. Pers.Indoor and Mobile Radio Comm., **(2010)**.