G3-PLC Time-frequency Combined Segment Reconstruction Coding Algorithm

Li Zhao, Xiaolu Jiao, Tong Zhu, Zhigang Liu and Feng Zhang

***Abstract*—**Due to the serious impact of the power line channel characteristics on the communication performance, especially in the case of strong noise interference the reliability of the communication system can't be guaranteed. In this case, a time-frequency combined segment reconstruction coding algorithm is proposed based on the G3-PLC standard, and the signal is decoded at the receiving end according to the maximum likelihood decoding criterion. The algorithm can effectively resist the interference of noise in time domain and frequency domain, improve the anti-noise performance of power line communication system, ensure the stability of the system and meet the high quality communication demand of power line. The simulation results show that compared with the current G3-PLC system, the proposed algorithm can improve the anti-noise performance about 8dB, and can achieve reliable communication in the case of strong noise interference.

This work was supported by the National Defense Foundation of China (Grant No.61271362&61671362); The general project Industrial Area of Shanxi Province, China (Grant No. 2017GY-081); The Natural Science Foundation of Shanxi Province, China (Grant No. 2017JM6041); Xi'an science and technology planning project(Grant No. CXY1341 (1)); Research Foundation of Education Bureau of Shanxi Province, China (Grant No. 2017JK0373).

Li Zhao is with the School of Electronic Information Engineering, Xi'an Technological University, Xi'an 710021, Shaanxi, China (corresponding author; e-mail: pilly_lily@126.com).

Xiaolu Jiao is with the School of Electronic Information Engineering, Xi'an Technological University, Xi'an 710021, Shaanxi, China.

Tong Zhu is with the School of Electronic Information Engineering, Xi'an Technological University, Xi'an 710021, Shaanxi, China.

Zhigang Liu is with the School of Electronic Information Engineering, Xi'an Technological University, Xi'an 710021, Shaanxi, China.

Feng Zhang is with the School of Electronic Information Engineering, Xi'an Technological University, Xi'an710021, Shaanxi, China

***Keywords*—** G3-PLC; noise interference; time-frequency combined segment reconstruction coding.

I. INTRODUCTION

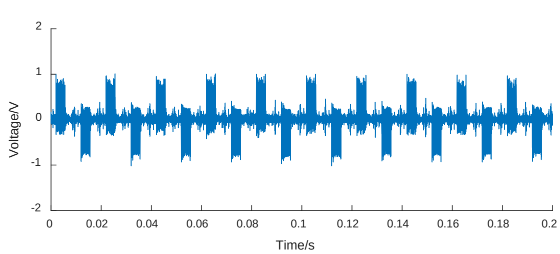
POWERline communication (PLC) technology is a process which utilizes the existing distribution network as a communication medium to achieve the transmission of information. Although the power line communication technology has been studied at home and abroad a few decades ago, the frequency selective fading characteristic, multipath characteristic and noise interference of power line channel have seriously hindered the development of PLC technology [1-3]. In recent years, with the rapid development of smart grid and smart home, power line carrier communication technology once again become the focus of the study.

In terms of the limitations of PLC technology, domestic and foreign communication alliance puts forward a series of communication standards about power lines, which is mainly divided into narrowband power line communication standard and broadband power line communication standard. The G3-PLC standard is a narrowband power line communication standard initiated by the French power grid transmission company developed by Maxim and Sagem Communications. The standard has a complete frame structure and the channel coding technology and error correction mechanism are efficient and reliable, and meet the challenges of the smart grid to communication technology in recent years [4-6]. However, the wiring environment of the domestic power line network is complicated and variable, at the same time the channel environment is harsh, especially the high noise of the low frequency band power line channel has serious interference to the communication performance of the power line [7-10]. When the actual communication standard is used for communication, the performance of the system will not meet the high quality of communication demands.

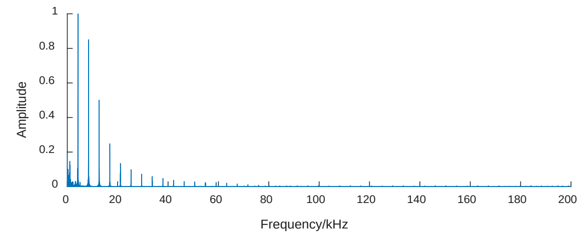
Aiming at the shortcomings of the current power line communication protocol, in this paper, an algorithm for resisting strong noise interference of power line in OFDM system is proposed. In the OFDM system, subcarrier is coded in time-frequency two-dimensional space. In order to ensure the accuracy of decoding, the maximum likelihood decoding criterion will be introduced at the receiving end to perform segment reconstruction and decoding operations. In the case of strong noise interference, the algorithm can improve the anti-noise performance of OFDM system and ensure the reliability of communication.

II. POWER LINE CHANNEL CHARACTERISTICS ANALYSIS

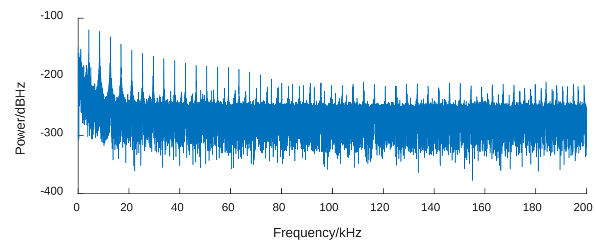
The quality of the power line carrier communication is mainly affected by the characteristics of the power line channel, in which the noise characteristic of the power line channel seriously interferes with the communication process. According to the research status of power line noise at home and abroad, the power line noise can be divided into colored background noise, narrowband noise, periodic pulse noise synchronized with power frequency, periodic impulse noise and impulse noise [11-15]. And the actual power line noise in the time domain is usually generated by the accumulation of several kinds of noise, especially for the random noise generates when the power grid in the high-power load access and cut out, and that will have a great unpredictable impact on the communication process. In order to analyze the noise characteristics of the power line channel, the field measurement noise of the power line is collected and its statistical characteristics are studied in the time domain and the frequency domain. In Fig.1 (a) is a group of power line practically measured noise time-domain waveforms. From observation of the time domain waveform of noise, the group of noise shows periodicity, continuity, and time variability, amplitude fluctuations between -1 ~1v. Fig.1 (b) shows the frequency domain waveform of field measurement noise, in the range from 0 to 50MHz noise intensity is large, and at some frequency there is a narrow band noise impact. Fig.1(c) shows the power spectral density of the field measurement noise. The average power spectral density in the entire frequency band is -280dBHz. In the low frequency range, due to the presence of narrowband shocks so the maximum power spectrum can achieve -120dBHz, and from power spectral figure, we can know that the practically measured power line noise is periodic noise and narrowband noise.



(a) Time Domain Waveform of Measured Power Line Noise



(b) Frequency domain waveform of measured power line noise



(c) Power Spectral Density of Measured Power Line Noise

Fig. 1. Analysis of noise in time domain and frequency domain

III. TIME-FREQUENCY JOINT SEGMENT RECONSTRUCTION CODING ALGORITHM

A. Time-frequency combined segment reconstruction coding based on G3-PLC

By analyzing the time domain and frequency domain of the practically measured power line channel noise respectively, the power line channel environment has the double complexity of the time-frequency domain, which will greatly affect the reliability of the communication. In order to further enhance the ability of the signal to adapt to the channel, it is necessary to introduce the effective coding technique in the time-frequency two-dimensional space at the same time resist the time-frequency interference of the channel noise to the system. In view of this situation, this paper, based on the G3-PLC communication standard, presents a time-frequency combined segment reconstruction algorithm. The algorithm is simple and reliable, which can effectively guarantee the communication performance of the PLC system under strong noise interference. The block diagram of the algorithm is shown in Fig. 2.

In Fig.2, the sender data is mapped by DBPSK/DQPSK and is represented by $B(k,l)$, which k represents the number of useful subcarriers and k is 1,2...36, l represents the number of OFDM symbols and l is 1,2...; In the frequency domain and time domain, $B(k,l)$ is divided into several paragraphs and then reconstructed, the coding principle is as follows:

In the frequency domain, segmentation is performed according to the number of active subcarriers in the G3-PLC standard and the power line channel environmental characteristics. In order to reduce the system's bit error rate while ensuring the communication rate, $B(k,l)$ is divided into 4 segments, with (1) represent:

$$B_i(l) = B(9(i-1)+1:9i,l) \quad 1 \le i \le 4 \tag{1}$$

The information after the segmentation is reconstructed and encoded, and the encoded matrix is represented $C(m,l)$. In the G3-PLC standard, the total number of subcarriers is 256 and the communication frequency bandwidth range is35.9kHz~90.6 kHz, the frequency band corresponds to the 23rd to 58th subcarriers. In frequency domain, the encoded information is stored in lines 23 to 58 of the $C(m,l)$, Therefore, the principle of $B_i(l)$ reconstruction coding as formula (2):

$$\mathbf{C}(m,l) = \begin{cases} 0 & 1 \le m \le 22 \\ B_i(l) & 23 \le m \le 31 \\ B_i(l) & 32 \le m \le 40 \\ B_i(l) & 41 \le m \le 49 \\ B_i(l) & 50 \le m \le 58 \\ 0 & 59 \le m \le 256 \end{cases} \tag{2}$$

In the traditional OFDM system, After IFFT modulation the transmitter signal becomes the plural signal, the receiver needs to use coherent detection technology to demodulate, which increases the complexity of the system. In order to reduce the complexity of the system and ensure the reliability of the system, on the basis of IFFT principle and performance, the signal $C(m,l)$ encoded by frequency domain segmentation is coded according to the formula (3)

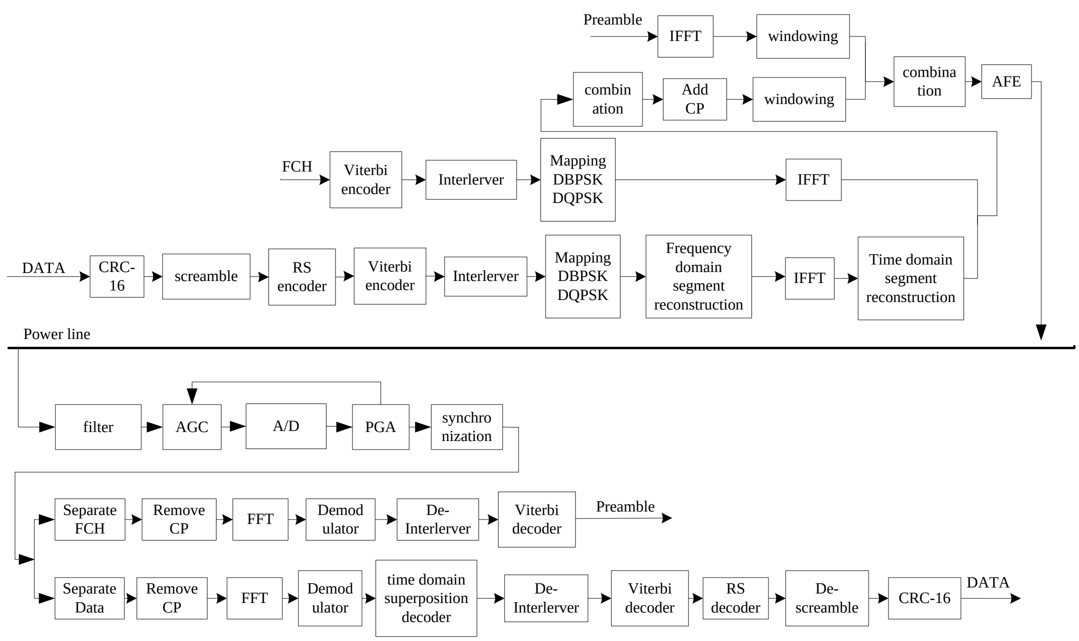


Fig. 2.G3-PLC physical layer diagram of loading time frequency joint reconstruction coding module

$$\mathbf{C}_1(m,l) = \begin{cases} c(m,l) & 1 \le m \le 128 \\ 0 & m = 129 \\ c(256-m+1,l) & 130 \le m \le 256 \end{cases} \tag{3}$$

The coded signal $C_1(m,l)$ is modulated by OFDM; the modulation process is as follows:

$$\mathbf{S} = IFFT\left[\mathbf{C}_1(m,l)\right] = (W_N)^{n`k}\mathbf{C}_1(m,l) \tag{4}$$

Where $W_N = e^{-j\frac{2\pi}{N}}$, $n`k = [0\,1\,2 \cdots N-1]^T [0\,1 \cdots N-1]$.

In order to improve the power line communication system against time domain noise interference, the signal is segmented and reconstructed in time domain. The encoding process is as follows (5) :

$$\mathbf{U} = \begin{cases} U(m,4l-3) = S(m,l) \\ U(m,4l-2) = S(m,l) \\ U(m,4l-1) = S(m,l) \\ U(m,4l) = S(m,l) \end{cases} \tag{5}$$

(5) Can be further abbreviated as:

$$\mathbf{U} = U(m,4l-n) = S(m,l) \quad (6)$$

Where $n = 0,1,2,3$ 。

The matrix U matrix in formula (6) is the information $\beta(k,l)$ has been encoded.

B. Time-frequency combined segment reconstruction decoding algorithm based on G3-PLC

In the G3-PLC standard, the transmitter increases the time frequency and joint segment reconstruction coding, and the receiver needs a valid decoding method to ensure the effectiveness of the algorithm. Since the maximum likelihood decoding criterion applies to this system and can effectively guarantee the accuracy of decoding, the receiver decodes according to the criterion.

$X = \{x_1, x_2, x_3 \cdots x_i\}$ is the information of the transmitter, and the corresponding terminal information is $Y = \{y_1, y_2, y_3 \cdots y_j\}$.

The channel transfer matrix is P:

$$P = \begin{bmatrix} P(y_1/x_1) & P(y_2/x_1) & \cdots & P(y_j/x_1) \\ P(y_1/x_2) & P(y_2/x_2) & \cdots & P(y_j/x_2) \\ \vdots & \vdots & \ddots & \vdots \\ P(y_1/x_i) & P(y_2/x_i) & \cdots & P(y_j/x_i) \end{bmatrix} \quad (7)$$

After the time-frequency two-dimensional joint segment reconstruction coding, the channel transmission matrix is extended to:

$$P_r = \begin{bmatrix} P_r(y_1/x_1) & P_r(y_2/x_1) & \cdots & P_r(y_j/x_1) \\ P_r(y_1/x_2) & P_r(y_2/x_2) & \cdots & P_r(y_j/x_2) \\ \vdots & \vdots & \ddots & \vdots \\ P_r(y_1/x_i) & P_r(y_2/x_i) & \cdots & P_r(y_j/x_i) \end{bmatrix} \quad (8)$$

Where $r = 1,2,3 \cdots 16$

The power line channel environment has stability in the short period. So, for the extended channel matrix, we solve expectation:

$$\overline{P} = \frac{1}{16}\sum_{r=1}^{16} P_r \quad (9)$$

According to the maximum likelihood decoding criterion, select the decoding function as $F(y_j) = x^* \left(x^* \in X, y_j \in Y\right)$ when the channel input symbol is equal probability distribution:

$$\overline{P}(y_j/x^*) \geq \overline{P}(y_j/x_i) \;\; (x_i \in X, x_i \neq x^*) \quad (10)$$

According to (10), if the information received by the receiving end is that the probability is the largest, it will be translated at the time of decoding, and the average bit error rate after decoding is minimized and can be effectively guaranteed the accuracy of decoding.

IV. SIMULATION RESULTS AND ANALYSIS

In order to compare the anti-noise performance of the G3-PLC standard with the time-frequency combined segment reconstruction module and the module without loading, the Monte Carlo method is used to simulate in MATLAB. In the whole experiment, DBPSK was chosen as the modulation method. In order to ensure the credibility of the experiment, 1000 simulation experiments are carried out to find the average bit error rate according to each group's SNR. The simulation parameters are shown in Table 1. The simulation results are shown in Fig. 3.

Tab.1.G3-PLC physical layer parameters

Sampling frequency(kHz)	400	Subcarrier spacing(kHz)	1.56
FFT points	256	Number of overlapping sampling points	8
The first subcarrier(kHz)	35.9	Number of cyclic prefix sampling points	30
The last subcarrier(kHz)	90.6	Number of leading sequence symbols	9.5

In order to compare the anti-noise performance of this algorithm with various types of forward error correction codes in the standard G3-PLC, six groups of simulation experiments were carried out in the environment of measured power line noise interference, followed by baseband OFDM system, loading convolution& interleaving coding, loading RS & convolution & interleaving coding, G3-PLC standard& time domain segment reconstruction coding, G3-PLC standard & frequency domain segmentation coding, G3-PLC standard & time-frequency domain joint Segment reconstruction coding, Simulation results shown in Figure 3.

The simulation results show that: ① the performance of OFDM system is significantly improved after loading the convolution and interleaving codes. After loading RS coding, the system can obtain the gain of 4dB, which indicates the various types of forward error correction coding in the G3-PLC standard can effectively improve the reliability of communication systems under certain conditions.

②By adding the segmentation reconstruction code in the time domain, the system can get 2dB gain compared to standard G3-PLC system. It shows that the time domain segmentation reconstruction algorithm can effectively resist the burst noise interference, but can not suppress the interference of color noise, so the reliability improvement is limited.

③According to the characteristics of power line noise, the thesis proposes segment reconstruction coding in the frequency domain, which is applied to the G3-PLC system to obtain a gain of 5dB. It shows that frequency-domain segmented reconstruction coding is an effective way to suppress power line noise, but its performance of suppressing white noise is limited in theoretically.

④Due to the multi-noise superposition characteristics of the actual channel, this paper combines the time domain segmentation reconstruction with the frequency domain segmentation reconstruction, and the time-frequency joint segmentation reconstruction algorithm is applied to the G3-PLC standard to get 8dB gain, which effectively improves the anti-noise ability of G3-PLC and ensure the reliable operation of the communication system under harsh channel environment.

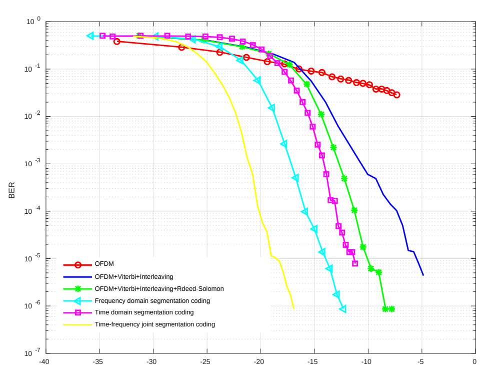


Fig. 3. Error characteristics of the system under measured noise

In order to further intuitively represent the performance of time-frequency combined segment reconstruction coding, a set of pictures are used as the information that were transmitted from the power line. The information is coded according to G3-PLC standard, time domain segment reconstruction coding, frequency domain segment reconstruction coding and time-frequency joint segment reconstruction coding. In order to reflect the anti-noise performance of time-frequency combined segment reconstruction, the SNR range is $-19 \le SNR \le -18$. The experimental results are shown in Fig.4.

Figure 4 shows that: In the case of serious noise interference, the received picture produces serious distortion, as shown in Figure (a). On the basis of the G3-PLC standard, the time domain segment reconstruction coding and the frequency domain segment reconstruction coding are loaded, and the bit error rate of the picture information at the receiving side is significantly reduced, the results are shown in Figure (b) and Figure (c). The picture information is transmitted by the system which is loaded time-frequency joint segmentation, the received picture is basically no noise interference, as shown in Figure (d). The experimental results show that the time-frequency combined segment reconstruction coding algorithm can realize high-quality communication when the power line is seriously disturbed by noise.

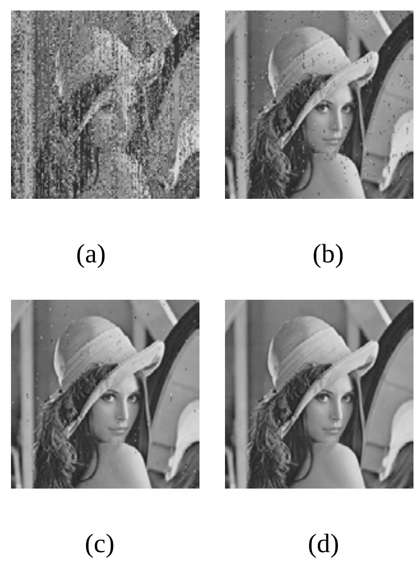


Fig. 4. Comparison of anti-noise characteristics of each system

V. CONCLUSIONS

Due to the power line channel noise has the characteristics of time-varying, periodicity and continuity in the time domain, and it has multi-noise superposition characteristic and frequency selection characteristic in the frequency domain, although various error correction coding modules introduced in the G3-PLC standard may improve system reliability, however, G3-PLC communication standard can not satisfy high-quality communication requirements in harsh channel environment with large noise interference, the time-domain segmentation reconstruction coding can improve the reliability to a certain extent, but because it is only applicable to random noise, so the performance is limited. Based on the in-depth analysis of the power line noise characteristics, this article propose a frequency-domain segmentation reconstruction coding algorithm to suppress colored background noise and organically combines it with the time-domain segmentation reconstruction coding algorithm, which can simultaneously suppress a variety of noise, compared with the standard G3-PLC system, the system performance achieves 8dB gain, which is an effective solution to improve the reliability of power line carrier communication in harsh channel environments.

REFERENCES

[1] Cai Wei, Le Jian, Jin Chao, et al. "Overview of the channel modeling methods of power-line carrier communication". *Power System Protection and Control*, vol. 40, no.10, pp. 529–551, 2012.

[2] Lai Zheng-tian. "Channel Characteristics Analysis and Simulation of Power Line Carrier Communication System". *Telecommunications for Electric Power System*, vol. 216, no.31, pp. 39-43, 2010.

[3] Qi Jia-jin, Chen Xue-ping, Liu Xiao-sheng. "Advances of Research on Low-Voltage Power Line Carrier Communication Technology". *Power System Technology*, vol.34, no.5, pp.161-173.2010.

[4] Yin Jian-feng, Ding Wen-bo, Wei Hua-yi, et al. "Research on PLC Communication Standards PRIME and G3-PLC". *Electrical Measurement & Instrumentation*, vol.51, no.13, pp.37- 42, 2014.

[5] Wu Xiao-meng, Liu Hong-li, Li Cheng, et al. "Performance analysis and improvement of forward error correction encoder in G3-PLC". *Journal of Computer Applications*, vol.33, no.2, pp. 393-396, 2013.

[6] Huang Zeng-xian, Wang Jin-hua. "Design and implementation of RS decoder based on G3-PLC". *Network and Communication*, vol.35 no.17, pp.68-72, 2016.

[7] Luo Han-wu, Cai Wei, Le Jian. "Analysis of influence factors on power-line communication channel characteristics". *Power System Protection and Control*, vol.41, no.7, pp.73-79, 2013.

[8] Xiao Yong, Fang Ying, Zhang Jie, et al. "Research on characteristics of low voltage power line communication channel". *Power System Protection and Control*, vol.40, no.20, pp.20-25, 2012.

[9] Liu Fang, Liu Sijiu, Zhang Liyong. "Channel Model and Simulation System of Low-Voltage PLC". *Journal of Harbin University of Science & Technology*, vol.11, no.4, pp.67-72, 2006.

[10] Zhang Hui-min, Wu Qing, Song Jian, et al. "Transmission characteristics modeling for medium voltage power line using multipath model". *Telecommunications for Electric Power System*, vol.29, no.190, pp.22-27, 2008

[11] Zhang Hong-xi, Zhang Xue-meng, Tai Xin. "Noise analysis and modeling research in power line channel". *Journal of Chongqing University of Posts and Telecommunications (Natural Science Edition)*, vol.25, no.5, pp.593-599, 2013.

[12] Liu Hai-tao, Zhang Bao-hui, Tan Lun-nong. "Study on noise characteristics of low voltage power networks in frequency region from 500 kHz to 10MHz and estimation of channel capacity". *Power System Technology*, vol.28, no.3, pp.69-74, 2004.

[13] Luo Jun-qing, Tan Zhou-wen. "A Simulation Study of Impulse Noise Reduction in OFDM-Based Low-voltage Power Line Communications". *Journal of Hunan University of Humanities, Science and Technology*, vol.33, no.4, pp. 117-123, 2016.

[14] Gu Zhi-ru, Liu Hong-li, Zhan Jie, et al. "Noise Suppression Investigation of a Narrowband Power Line Communication for Smart Grid". *Transactions of china electro technical society*, vol.29, no.11, pp. 269-276, 2014.

[15] Cai Wei, Le Jian, Jin Chao. "Overview of the channel modeling methods of power-line carrier communication". *Power System Protection and Control*, vol.40, no.10, pp.149-155, 2012.

Li Zhao was born on Apr. 16th, 1981. She received the PhD degree in microelectronics and solid-state electronics from Xi'an University of technology. Currently, she is a researcher (assistant professor) at Xi'an Technological University, China. Her major research interests include Optical communication an power line communication

Xiaolu Jiao was born on Feb.22th, 1992. She will receive the MD degree in communication and information system from Xi'an Technological University. Currently, she is a graduate student at Luo Yang Normal University, China. Her major research interests include signal processing and power line communication.

Tong Zhu was born on Jan.20,1995. He will receive the MD degree in communication and information system from Xi'an Technological University. Currently, he is a graduate student at HeFei Normal University, China. His major research interests include signal processing and visible light communication.

Zhigang Liu was born on March 15th 1993. He will receive the MD degree in communication and information system from Xi'an Technological University. Currently, he is a graduate student at Anyang Institute of Technology, China. His major research interests include signal processing and Visible light communication.

Feng Zhang was born on Jun. 17th, 1979. He received the MD degree in Control theory and control engineering from Xi'an Technological University. Currently, he is a researcher (assistant professor) at Xi'an Technological University. His major research interests include modern signal processing, embedded development and power line communication.