Anti-noise Algorithm Based on Time Domain Superposition in G3-PLC System

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

***Abstract*—**Because of the characteristics of multipath and fading, especially in the case of serious noise interference, G3-Power Line Communication (PLC) standards cannot satisfy the high quality communication requirements. In order to improve the reliability of power line communication, time domain superposition coding module based on the G3-PLC standard is introduced in this paper. By appending time domain superposition coding to the baseband OFDM signal, system capacity against multipath and fading can be improved. Secondly, simulation is carried out in Gaussian channel and multipath channel environment respectively. The results demonstrate that the PLC platform with time domain superposition coding module can obtain about 3~4dB gain in Gaussian channel and 4dB gain in multipath channel. Finally, in order to further intuitively represent the performance of time domain superposition coding algorithm, 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 and time domain superposition coding separately. The experimental results show that the time domain superposition coding algorithm can realize high-quality communication when the power line is seriously disturbed by noise.

***Keywords*—**G3-Power Line Communication Standard, Noise Interference, Time Domain Superposition Coding.

I. Introduction

POWER line communication (PLC) has long been proposed, and some communication standards have been formed in foreign countries. The G3-PLC standard has a perfect frame structure, and supports IPv6 protocol. It is suitable for medium and low speed communication in the strong noise environment, with characteristics of full compatibility, anti-interference, high-speed transmission, flexible network construction and information security, and mainly used in smart meter reading system [1]. However, in recent years, with the concepts of smart grid and intelligent home were proposed, the traditional PLC technology has been unable to meet the high quality of communication needs, so it must be optimized [2-4].

On the basis of the G3-PLC standard, the performance of the communication system can be optimized by various methods [5]. Since the signal is sensitive to noise interference, the clipping method is adopted to reduce the impulse noise, and the KLT feature space decomposition is adopted to restrain the back-ground noise. Although this scheme can reduce the influence of power line noise on communication system, only about 1 dB is improved on performance after noise suppression, and because of the complexity of noise, parameters in the noise scheme only can be obtained experimentally, which will make the system scheme more complicated and produce more errors. Literature [6] is proposed to improve the reliability of the system from the coding method, using time-frequency two-dimensional interleaving algorithm instead of the packet interleaving algorithm to reduce the continuous error caused by frequency selective fading in frequency domain and impulse noise in time domain. This method improves the bit error rate (BER) performance of the system by about 2 dB. However, the improved interleaving algorithm is more complicated than the packet interleaving algorithm, and interleaving coding increases the processing delay of the system, and the larger the interleaving depth, the greater the delay.

The above techniques optimize the physical layer model of G3-PLC standard on the basis of OFDM modulation. However, due to the complex channel environment in PLC, the signal will be more susceptible to noise interference in the poor channel environment especially; the optimization methods mentioned in literature [5] and [6] will not meet the communication needs. In view of this situation, the time domain superposition technique is used in this paper to increase the anti-multipath fading ability of the system by adding time domain superposition coding to the baseband OFDM signal. The simulation results show that the proposed method can improve system anti-interference performance distinctly.

A. Mathematical model of channel

Power line is used as transmission medium in communication. Due to the unpredictability of channel environment, the influence of channel on signal will not be able to estimate. So, the first task of PLC is to establish the

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corresponding channel model and analysis the influence of channel on communication process [7].

In order to simulate the channel environment on power line, Dostert and Zimmermann [8] proposed power line multipath channel model, which provides a reliable theoretical basis for G3-PLC. Assuming that the frequency response of the channel model is $H(f)$

$$H(f)=\sum_{i=1}^{N}\left|g_i(f)\right|\cdot e^{\phi_{g_i}(f)}\cdot e^{-(a_0+a_1 f^k)d_i}\cdot e^{-j2\pi f\tau_i} \qquad (1)$$

The power line channel polynomial model can be divided into three parts: $\left|g_i(f)\right|e^{\phi_{g_i}(f)}$ indicates the weighting factor; $e^{-(a_0+a_1 f^k)d_i}$ indicates the fading part; $e^{-j2\pi f\tau_i}$ indicates the delay part. Formula (1) can be abbreviated as

$$H(f)=\sum_{i=1}^{N} g_i e^{-(a_0+a_1 f^k)d_i} e^{-j2\pi f\tau_i} \qquad (2)$$

where i indicates the number of paths, which equals 1 while the model owning shortest delay, and N indicates the number of paths at which the signal can reach the receiver, which is referred as multipath number, and a_0 and a_1 indicate fading parameter, and τ_i indicates delay parameter, and d_i indicate the length of path i ,and $v_p = c_0/\sqrt{\varepsilon_r}$ =150$m/\mu s$ is the phase speed of the cable, where c_0 is light speed, ε_r is dielectric constant.

According to formula (2), we establish a model of channel, and the spectral characteristics curves are shown in Fig.1 and Fig.2.

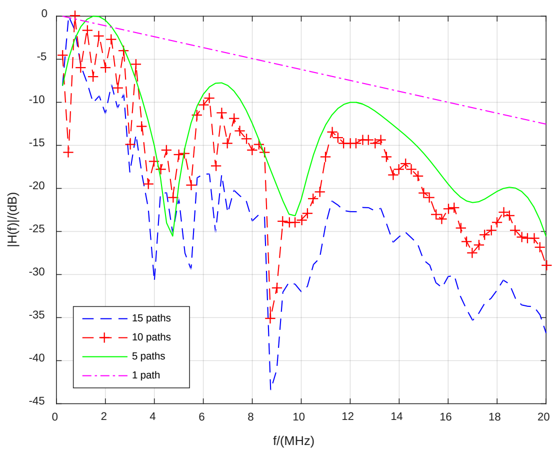


Fig.1. Frequency domain fading characteristics of multipath channel model

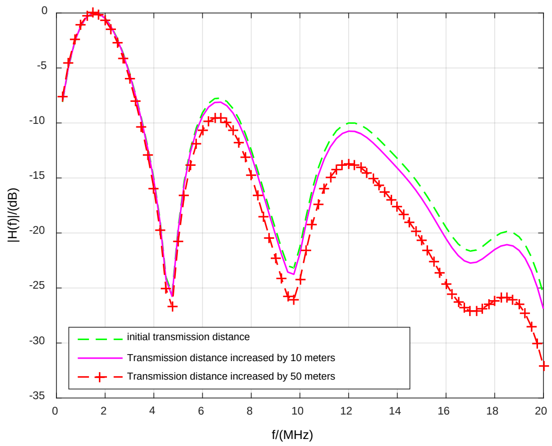


Fig.2. Fading effects of transmission distance on Multipath channel model

According to the simulation results of Fig.1, power line channel has multipath effect and frequency selective fading characteristics, and the latter one becomes more obvious as the number of multipath i increases. Fig.2 shows that power line channel has fading characteristics, and the signal will produce a serious decline as the transmission distance increases. The simulation experiment shows that PLC environment is bad, so some effective coding methods are necessary to increase system reliability.

B. Measured channel model

Due to the complex architecture environment and various load access of the power line network, the domestic power line network communication environment is very poor, and the development of power line communication technology in China has been seriously hindered.

In order to analyze the noise characteristics of the domestic power line channel, a collection scheme of noise in the low voltage power line network is designed in the laboratory environment, and one group of noise data is selected for experimental analysis. The main equipments required are coupling module, noise measuring device and noise source (some electrical equipment in laboratory environment). The test environment is the 220V power line channel in the laboratory. The loads of the power line are mainly the computer, oscilloscope and electric kettle in the laboratory environment. The schematic diagram of noise measurement in low voltage power line network is shown in Fig.3.

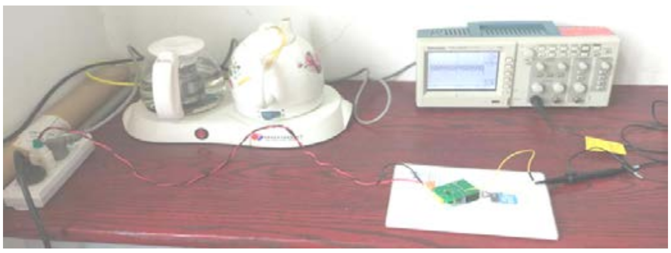
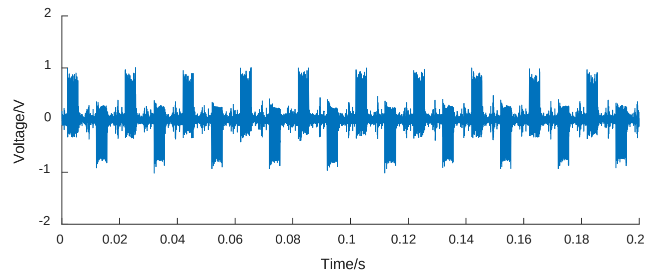
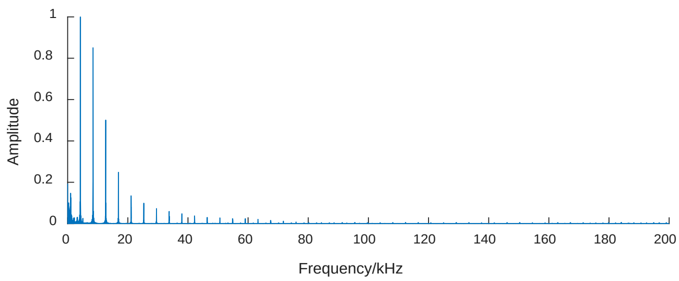


Fig.3. Power line noise measurement connection diagram

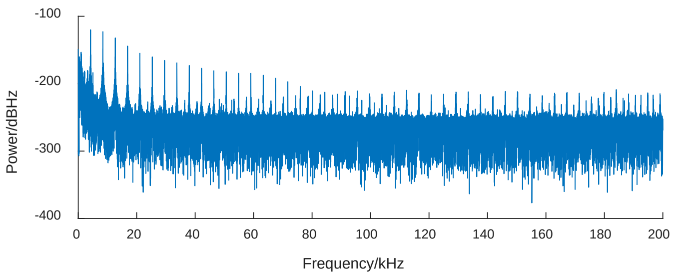
As the actual power line noise in the time domain is usually generated by the accumulation of several kinds of noise, especially for the random noise generates when the power grid in the high-power load access and cut out, and that process. In order to analyze the noise characteristics of the power line 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.4 (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.4(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.4(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. 4. Analysis of noise in time domain and frequency domain

will have a great unpredictable impact on the communication

II. Time Domain Superposition Coding on G3-PLC

A. The Signal structure of G3-PLC

The data frame structure in the G3-PLC standard is shown in Fig.5, and the physical layer model is shown in Fig.7. The data frame structure in Fig.5 is mainly composed of three parts: the preamble, the FCH (Frame Control Header) and the data.

Preamble is used to assist the automatic gain control, signal timing synchronization and channel estimation control. The Preamble shown in Fig.7 contains the correct information of the signal modulation and demodulation, and the DATA represents the communication information that needs to be transmitted through the power line.

In Fig.5, FCH information is placed after the Preamble information. There are 13 FCH symbols in the standard frame structure, which are essentially the same as data bits. In each data frame, FCH symbols are used to carry the information needed for demodulation, such as DATA frame length and data frame mapping mode. In the G3-PLC physical layer model, the effective information DATA supports two mapping methods DBPSK/DQPSK, but for FCH information, the most reliable DBPSK mapping method will be adopted.

In order to reduce the impact of ICI and ISI in the communication system, a certain length of protection interval and cyclic prefix CP are set in each frame, usually the protection interval can be replaced by a partial CP directly, but the information in the CP is replaced by 30 information in the tail of each symbol because of the strict orthogonality between the subcarriers in the modulation process. In addition, there are overlapped in each frame, and the overlap length is affected by the length of the window. The overlap length is 8 in G3-PLC system. For example, the end 8 bits of Preamble information overlap with the first 8 bits of the first FCH data segment; there are overlaps between adjacent symbols in each Preamble and FCH data segment, but there is no such overlap for the end of the last DATA segment.

B. G3-PLC physical layer model with time domain superposition coding module

Traditional PLC generally uses FSK single carrier modulation, which has poor characteristics of anti-interference. Comparatively, G3-PCL standard uses OFDM modulation, which makes the system against multipath delay effectively, reducing the interference between signals and improving the spectrum utilization factor significantly [9]. In order to further improve the system's anti-interference performance, G3 standard mainly rely on scrambling code, RS coding, Viterbi coding, interleaving coding to achieve error detection and correction functions for system. Considering the original coding method in the G3 standard can't guarantee the reliability of the communication in the high noise interference PLC channel, the time domain superposition coding module is added on the basis of the G3 standard. The G3-PLC standard physical layer model loaded with time domain superposition coding module is shown in Fig.7.

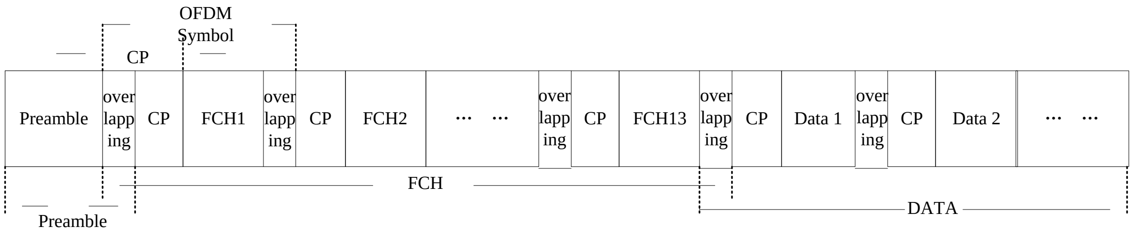


Fig. 5. The signal structure of G3-PLC

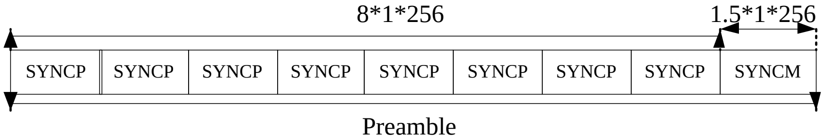


Fig. 6. The structure of Preamble

C. G3-PLC time domain superposition coding principle

The G3-PLC standard adopts OFDM modulation scheme. Assuming that T represents the duration of OFDM symbol, the sum of the N way sub-signals in OFDM system can be expressed as [10]:

$$s(t) = \sum_{n=0}^{N-1} B_n \cdot e^{j2\pi f_n t} \quad (t \in [0,T]) \tag{3}$$

Where f_n indicates the n-th sub-carrier's frequency, and its expression is

$$f_n = f_0 + \frac{n}{T} \quad (n = 0,1,2,\cdots,N-1) \tag{4}$$

When sampling rate is T/N, assuming that $t = k \cdot T/N$, then

$$s(k) = \sum_{n=0}^{N-1} B_n \cdot e^{j2\pi n \frac{k}{N}} \quad (k = 0,1,2,\cdots,N-1) \tag{5}$$

In G3-PLC standard, the OFDM modulation scheme is realized by IFFT. Assuming the data before IFFT can be expressed as a matrix $\boldsymbol{B}(h,l)$, then it is a conjugate symmetric matrix with the below expression

$$\boldsymbol{B}(h,l) = \begin{cases} \boldsymbol{A}(h,l) + \boldsymbol{C}(h,l)\,j & 1 \le h \le \dfrac{N}{2} \\ \boldsymbol{B}^*(N-h+1,l) & \dfrac{N}{2}+1 \le h \le N \end{cases} \tag{6}$$

where

$$\boldsymbol{A}(h,l) = \begin{vmatrix} a(1,1) & a(1,2) & \cdots & a(1,l) \\ a(2,1) & a(2,2) & \cdots & a(2,l) \\ \vdots & \vdots & \ddots & \vdots \\ a(h,1) & a(h,2) & \cdots & a(h,l) \end{vmatrix}$$

$$\boldsymbol{C}(h,l) = \begin{vmatrix} \mathrm{c}(1,1) & c(1,2) & \cdots & c(1,l) \\ c(2,1) & c(2,2) & \cdots & c(2,l) \\ \vdots & \vdots & \ddots & \vdots \\ c(h,1) & c(h,2) & \cdots & c(h,l) \end{vmatrix}$$

Taking IFFT on $\boldsymbol{B}(h,l)$, then

$$\boldsymbol{S} = \mathrm{IFFT}\left[\boldsymbol{B}(h,l)\right] = (W_N^{-kn})\boldsymbol{B}(h,l) \tag{7}$$

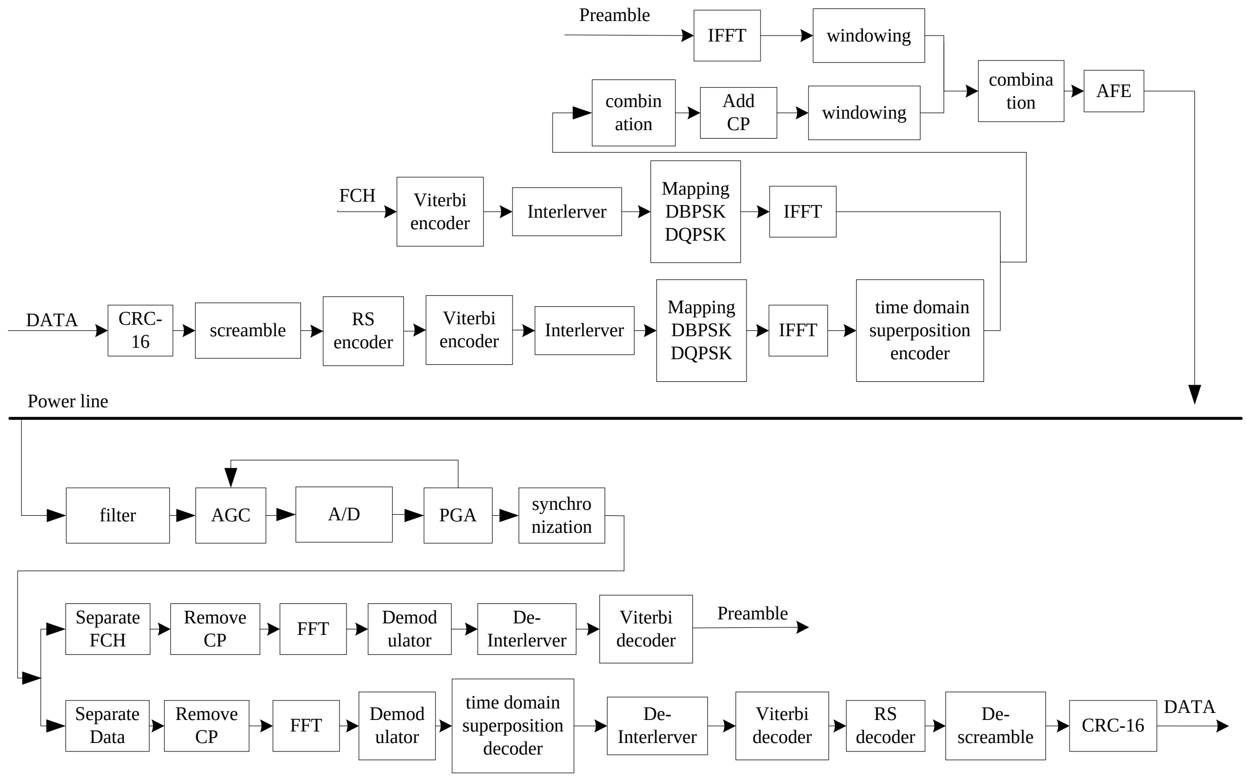


Fig.7. G3-PLC physical layer diagram of loading time domain stacking module

Where

$$W_N^{-kn} = e^{j\frac{2\pi k}{N}} \tag{8}$$

After IFFT operation, the signal is in time domain. In formula (7), $S(u,v)$ indicate each element of matrix $\boldsymbol{S}$. If an OFDM symbol is represented by each column of this matrix, and assuming $\boldsymbol{U}$ indicates the matrix which can be obtained by each OFDM symbol after four times time domain superposition coding, then it can be expressed as follow.

$$\boldsymbol{U} = \begin{cases} \boldsymbol{U}(u,4i\text{-}3) = \boldsymbol{S}(u,i) \\ \boldsymbol{U}(u,4i\text{-}2) = \boldsymbol{S}(u,i) \\ \boldsymbol{U}(u,4i\text{-}1) = \boldsymbol{S}(u,i) \\ \boldsymbol{U}(u,4i) = \boldsymbol{S}(u,i) \end{cases} \quad (1 \le i \le v) \tag{9}$$

An abbreviated form is

$$\boldsymbol{U} = \boldsymbol{U}(u,4i-j) = \boldsymbol{S}(u,i) \tag{10}$$

Where $1 \le i \le v,\ 1 \le u \le 256,\ j = \{0,1,2,3\}$

D. G3-PLC time domain superposition decoding principle

In order to guarantee the reliability of the coding algorithm, valid decoding criteria must be selected in receiver for decoding operations. The traditional decoding algorithm is to take the mean for the superimposed coding data. However, this method will produce serious decoding errors in the case of high noise interference. In this case, we select maximum likelihood decoding criterion to decode the signal in receiver. Assuming the useful information in OFDM symbol before the time domain superposition coding in transmitter can be expressed as $\boldsymbol{X} = \{x_1, x_2, x_3 \cdots x_n\},(n = 36)$, and the information in receiver is $\boldsymbol{Y} = \{y_1, y_2, y_3 \cdots y_m\},(m = 36)$, then the channel transfer matrix can be expressed as

$$\boldsymbol{P} = \begin{bmatrix} p(y_1/x_1) & p(y_2/x_1) & \cdots & p(y_m/x_1) \\ p(y_1/x_2) & p(y_2/x_2) & \cdots & p(y_m/x_2) \\ \vdots & \vdots & \ddots & \vdots \\ p(y_1/x_n) & p(y_2/x_n) & \cdots & p(y_m/x_n) \end{bmatrix} \tag{11}$$

The system channel with time domain superposition coding is equivalent to the extended channel. Assuming that the signals are independent of each other, after four times time domain superposition coding, the channel transfer matrix can be expressed as

$$\boldsymbol{P}_i = \begin{bmatrix} p_i(y_1/x_1) & p_i(y_2/x_1) & \cdots & p_i(y_m/x_1) \\ p_i(y_1/x_2) & p_i(y_2/x_2) & \cdots & p_i(y_m/x_2) \\ \vdots & \vdots & \ddots & \vdots \\ p_i(y_1/x_n) & p_i(y_2/x_n) & \cdots & p_i(y_m/x_n) \end{bmatrix} \tag{12}$$

Where $i = \{1,2,3,4\}$.

Since the power line channel characteristics have flatness in a short time, the expectation of extended channel matrix can be obtained by the following formula.

$$\overline{\boldsymbol{P}} = \frac{1}{4}\sum_{i=1}^{4}\boldsymbol{P}_i \tag{13}$$

According to the principle of maximum likelihood decoding criterion, the decoding function is $F(y_j) = x^*$, where $x^* \in X$, $y_j \in Y$, and when the channel input follows the equal probability distribution:

$$\bar{P}(y_j / x^*) \geq \bar{P}(y_j / x_i) \quad (x_i \in X, x_i \neq x^*) \qquad (14)$$

which means that the probability of sending x^* is the largest under the condition of receiving y_i. And y_i will be decoded as x^*. At this point the average error rate is minimal. According to formula (14), the maximum value corresponding to the input symbol from channel matrix will be the symbol information sent from source.

III. Simulation Results and Analysis

In order to verify the performance of the PLC physical layer model with time domain superposition module and the original G3 model, we performed the various original coding algorithms in G3 standard and the time domain superposition coding algorithm by simulation. The parameters are shown in Tab 1.

Table 1. G3-PLC physical layer parameters

Parameter type	Size	Parameter type	Size
Sampling frequency (kHz)	400	Sub-carrier interval (kHz)	1.56
IFFT points	256	Number of overlapping sampling points	8
First sub-carrier (kHz)	35.9	Number of cyclic prefix sampling points	30
Last sub-carrier (kHz)	90.6	Number of preamble	9.5

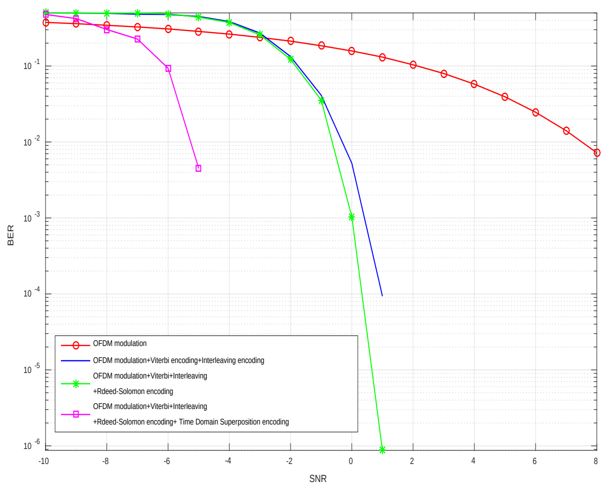


Fig.8. The performance of system in Gauss channel

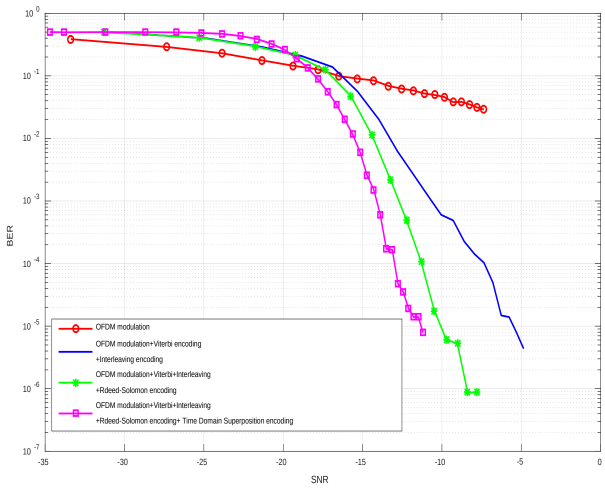


Fig.9. Performance of the system in Gaussian & multipath delay channel

As shown in Fig.8, when the data bit modulation mode is DBPSK, the simulation experiment is carried out in Gaussian channel environment. The results show that when SNR equals -1 dB, original coding methods in G3-PLC standard can achieve the BER as 10^{-2}, however, the method of adding time domain superposition coding module on the basis of G3-PLC standard achieves 10^{-2} when SNR equals -5 dB, which can obtain about 4 dB gains comparatively. Experiments show that adding time domain superposition coding module on communication system can effectively resist strong noise interference on the basis of G3-PLC standard.

As shown in Fig. 9, in order to further illustrate the ability of time domain superposition coding to adapt to power line channel, we append multipath and delay characteristics to Gaussian channel. Multipath number is 4, the normalized intensity relative to the transmitted signal of each path are [0.12 0.224 0.124 0.25], and the delays are [1 3 5 7].

When the data bit modulation mode is DBPSK, the simulation experiment is carried out in Gaussian channel environment appended with multipath and delay characteristics. The results show that when SNR equals 15 dB, original coding methods in G3-PLC standard achieve the BER as 10^{-3}, however, the method of adding time domain superposition coding module on the basis of G3-PLC standard achieves 10^{-3} when SNR equals about 11 dB, obtaining about 4 dB gains comparatively. Experiments show that adding time domain superposition coding module on communication system can not only reduce the high noise interference but also effectively resist the influence of multipath and delay characteristics of power line channel.

In order to further intuitively represent the performance of time domain superposition coding algorithm, 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 and time domain superposition coding separately. In order to reflect the anti-noise performance of time domain superposition coding algorithm, the SNR range is $-19 \le SNR \le -18$. The experimental results are shown in Fig.10.

Fig.10 shows that: In the case of serious noise interference, the received picture produces serious distortion, as shown in Fig.(a). On the basis of the G3-PLC standard, the time domain superposition coding is loaded, and the bit error rate of the picture information at the receiving side is significantly reduced, the results are shown in Fig.(b). The experimental results show that the time domain superposition coding algorithm can realize high-quality communication when the power line is seriously disturbed by noise.

(a)

(b)

Fig. 10. Comparison of anti-noise characteristics of each system

IV. Conclusion

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. The original error correction coding methods of G3-PLC standard can effectively ensure reliable transmission of the signal when the noise is comparatively weak. But when the noise environment is worse, the communication standard can't show its superiority. In view of this situation, the time domain superposition coding algorithm is appended on the G3-PLC standard, and simulation experiments have been performed. The results show that the system obtains a gain of 4 dB when the G3-PLC standard is appended with time domain superposition coding, and the algorithm can not only resist the interference of high noise, but also can effectively resist the influence of multipath and delay. In the practical application, the power line noise interference is more serious, it is considerable to append time domain superposition coding to G3-PLC standard for communication performance improvement.

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