Pilot Design of OFDM/OQAM System Based on Interference Cancellation

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Abstract—**In order to suppress the imaginary intrinsic part interference of OFDM/OQAM system in radio channel, a new pilot design approach is proposed. The new design approach can suppress the intrinsic imaginary interference in quasi-stationary channel and reduce the pilot peak power due to sparse data forms. This paper analyzes the reason why the imaginary intrinsic interference produces in the PLC (power line communication) channel and the new pilot eliminates the imaginary intrinsic interference. Compared with the pilot design of OFDM/CP,OFDM/OQAM system, it is verified that the new pilot design approach is better than OFDM/CP ,IAM-R,IAM-I and almost the same as IAM-new under MATLAB simulation platform in the PLC channel with the same channel estimation and equalization mode.**

Keywords- OFDM/OQAM; pilot design; PLC; IOTA; interference cancellation

I. INTRODUCTION

As suggested in [1-3], OFDM/OQAM(Orthogonal frequency division multiplexing offset quadrature amplitude mapping, OFDM/OQAM) has, different from OFDM/CP, the advantage of resisting ISI (inter symbol interference, ISI)and ICI (inter carrier interference, ICI)，having no cyclic prefix ，having low out of band radiation in comparison with OFDM/CP [4]. In multipath transmission channel, however, OFDM/OQAM signal is easily susceptible to the imaginary intrinsic interference，which leads to the fact that OFDM/CP pilot design cannot be directly applied to the OFDM/OQAM. So the basic of the block pilot and the discrete pilot can be found in[5-6],it is more recently seen that the pilot based on the equivalent power maximization, such as the IAM-R[7],IAM-I[8],IAM-new[9], the pilot design based on interference cancellation[10,11]has also received more and more attentions. The new pilot design based on the interference cancellation is not required a priori knowledge of the pulse function and can avoid complicated calculations. In addition, the peak power of the pilot can be reduced by sparse data form.

In the Section Ⅱ, the mathematical model of OFDM/OQAM systems is established in the multipath channel, the imaginary intrinsic interference how to produce is also discussed. In the Section Ⅲ, a new design approach of pilot is presented. In the Section Ⅳ, the new pilot is simulated in the PLC channel[12] in comparison with the OFDM-CP and OFDM/OQAM methods.

II. OFDM/OQAM IN MULITPATH FADING CHANNEL

A. The basic principle of OFDM/OQAM

Complete orthogonal basis does not exist in the complex domain of the OFDM/OQAM, while orthogonal basis exists in the real domain, which suggests that the transmitted symbols must be real [13-14]. OFDM/OQAM structure diagram is shown as Fig .1.
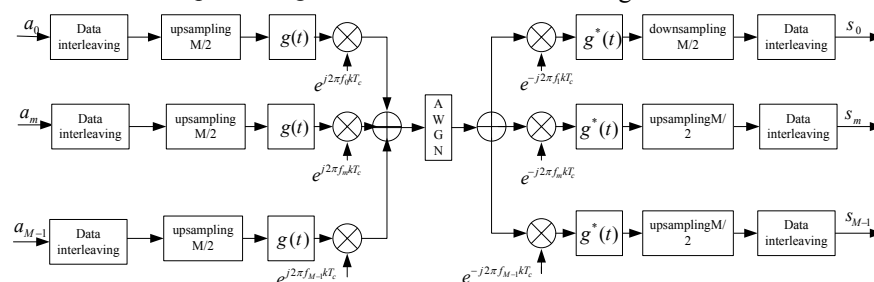

Figure 1.   OFDM/OQAM system structure diagram

In Fig .1, $g(t)$ is the transmitter shaping filter, while $g^*(t)$ is the receiver math filter. In the continuous form，the transmitted signal can be expressed as

$$s(t) = \sum_{n=-\infty}^{\infty} \sum_{m=0}^{M-1} a_{m,n} g_{m,n}(t) e^{j\Phi_{m,n}}$$

$$= \sum_{n=-\infty}^{\infty} \sum_{m=0}^{M-1} a_{m,n} e^{j\pi(m+n)/2} e^{j2\pi F_0 t} g(t-n\tau_0) e^{j\Phi_{m,n}} \quad (1)$$

Where, M is the number of sub-carrier, $F_0 = 1/T_0 = 1/2\tau_0$ is the sub-carrier spacing, g is the pulse, $\Phi_{m,n}$ is the additional phase. In the ideal channel, the real signal reconstruction should satisfy the following relationship:

$$\langle g_{m,n}(t), g_{p,q}(t) \rangle_R = \mathrm{Re}\{\int_R g_{m,n}(t) g_{p,q}^*(t) dt\}$$

$$= \mathrm{Re}\{e^{j((m+n-p-q)+(m-p)(n-q))\frac{\pi}{2}} A_g((q-n)\tau_0,(p-m)\upsilon_0)\} \quad (2)$$

$$= \delta_{m,p}\delta_{n,q}$$

B. OFDM/OQAM system in the multipath channel

The PLC channel is usually quasi static multipath. The impulse response of the channel model is simulated by a fixed coefficient of the FIR filter impulse response, i.e. $h(t)$, additive white Gauss noise is set to $n(t)$. The schematic diagram of the transmitter and receiver signals as Fig .2. The receiver of the base-band signal can be expressed as (2):
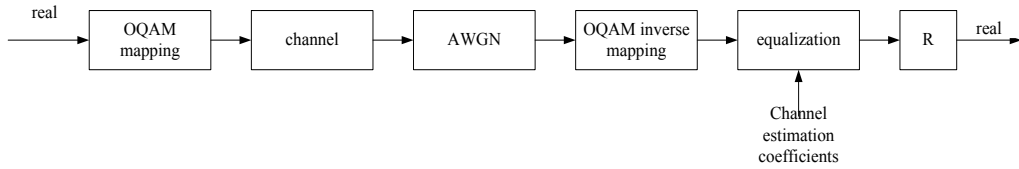
$$y(t) = (h*s)(t) + n(t) \quad (3)$$

It is also be written as:

$$y_{wn}(t) = \sum_{n=-\infty}^{\infty} \sum_{m=0}^{2N-1} a_{m,n} g_{m,n}(t) H_m^c \quad (4)$$

Where, $H_m^c = \int_0^\Delta h(t,\tau) g(t-\tau-n\tau_0) e^{-2j\pi m F_0 t} d\tau$.

Assuming the demodulated signal in the position of (m_0, n_0) where m_0 is the sub-carrier and n_0 is the symbol, regardless of the noise, the received signal is $y_{m_0,n_0}^c = <y | g_{m_0,n_0}>$. After calculation,

$$y_{m_0,n_0}^c = H_{m_0,n_0}^c a_{m_0,n_0} +$$
$$\sum_{(p,q)\neq 0} a_{m_0+p,n_0+q} H_{m_0+p,n_0+q}^c <g>_{m_0+p,n_0+q}^{m_0,n_0} \quad (5)$$

$$I_{m_0,n_0} = \sum_{(p,q)\neq 0} a_{m_0+p,n_0+q} \frac{H_{m_0+p,n_0+q}^c}{H_{m_0,n_0}^c} <g>_{m_0+p,n_0+q}^{m_0,n_0} \quad \text{is a}$$

complex value, so the estimation value is:

$$\hat{a}_{m_0,n_0} = R\{y_{m_0,n_0}^c\}$$
$$= a_{m_0,n_0} + R\{I_{m_0,n_0}\} \quad (6)$$

Here $<g>_{m_0+p,n_0+q}^{m_0,n_0} = A_g(-q\tau_0, p\upsilon_0)$, the interference part (IRS, Interference between Real Symbols)is often called as the imaginary intrinsic interference, which is caused by the complex coefficients of the channel.

Figure 2.   Schematic diagram of OFDM/OQAM channel estimation and equalization

III.   A NEW PILOT DESIGN METHOD

There are two mainly methods in the pilot design of OFDM/OQAM: one is based on the interference cancellation, the other one is based on the equivalent maximum power. The latter takes part of the interference as the power, which can obtain larger pilot power to decrease the IRS and AWGN. The new method is based on the interference cancellation, which could cancel adjacent channel interference. The new design based on interference cancellation can be divided into two steps.

Assuming the pulse shaping function has good time frequency localization ability (TFL). A function is defined, i.e. $\Omega_{\Delta m,\Delta n}$, in order to explain the subsequent instructions. It can be expressed as (7),

$$\Omega_{\Delta m,\Delta n} = \{(p,q), |p| \leq \Delta m, |q| \leq \Delta n|\} \quad （7）$$

In addition, $\Omega_{\Delta m,\Delta n}^* = \Omega_{\Delta m,\Delta n} - \Omega_{0,0}$ [12], then, as $|p|$ and $|q|$ increasing, $A_g(-q\tau_0, p\upsilon_0)$ becomes very close to zero, e.g., in the IOTA, when $(p,q) \notin \Omega_{1,1}$ and $<g>_{m_0+p,n_0+q}^{m_0,n_0} | \leq 0.04$, then:

$$\frac{\sum_{(p,q)\notin \Omega_{1,1}} |A_g(-q\tau_0, p\upsilon_0)|}{\sum_{(p,q)\in \Omega_{1,1}^*} |A_g(-q\tau_0, p\upsilon_0)|} \approx 0.02 \quad (8)$$

A good TFL pulse function can eliminate part of IRS. However, the imaginary intrinsic interference will become larger and larger in the multipath or higher order constellation mapping. Therefore, the adjacent channel imaginary intrinsic interference should be given full of consideration, especially, in the $\Omega_{\Delta1,\Delta1}^*$.
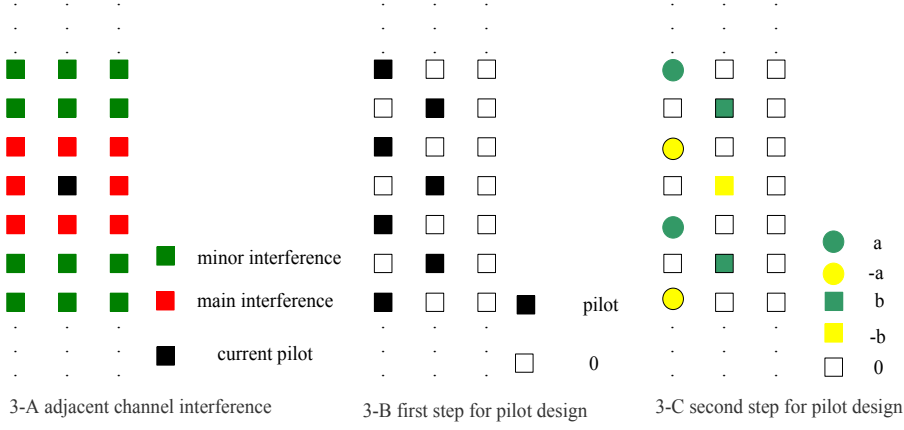
Figure 3. New pilot design ideas

The adjacent pilot interference is shown in Fig .3-a, when the pilot of the current point (black portion) is estimated, the red pilot which is the main interference and the green pilot will affect the accuracy of estimation of the current channel. The new pilot design will eliminate the intrinsic interference of these red parts. Steps are as follows:

Step one: following the block pilot mode of the OFDM/OQAM, zeros are paced between the pilot points. As shown in Fig .3-B, the position with"0"has no interference, but other parts, such as the pilot position adjacent in the other row has still interference.

Step two: each row of data is opposite value in order to eliminate the interference of the Euclidean distance which is equal to $\sqrt{2}$. It is showed as Fig .3-c3 that the same color is the same value, the other is opposite value in the same column .The complex form is used to distinguish the previous. It is called as OQAM-C and shown in Fig .4-D.
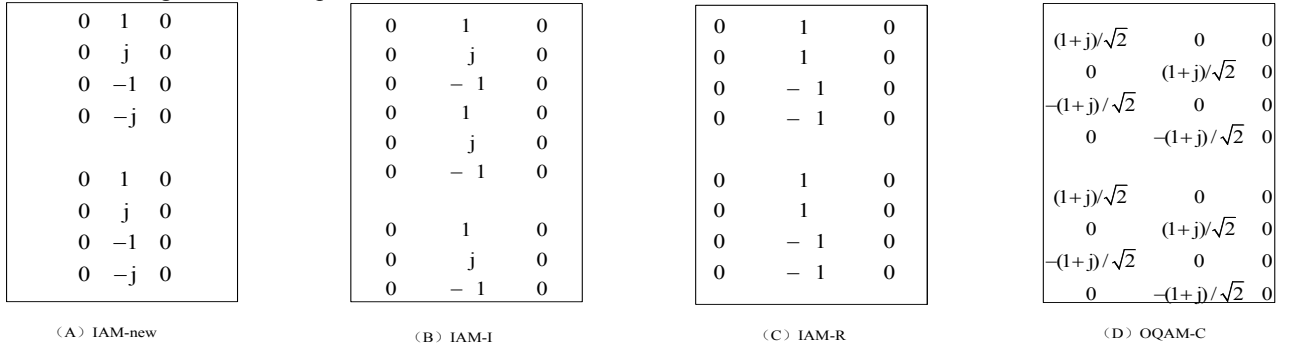

Figure 4. Schematic diagram of the pilot

IAM-I, IAM-R, IAM-new are designed by the maximize power criteria, in which the IAM-new can eliminate interference within $\Omega^{*}_{\Delta 1,\Delta 1}$, while the IAM-I and IAM-R cannot. Their pilot design is shown in Fig 4-A, 4-B, 4-C.

Two-part channel estimation values can be obtained in the form of OQAM-C:

$$\begin{cases} y^1 = H^{c_1}_{2m_0,n_0-1}\left(a_{2m_0,n_0-1} + \mathrm{j}a^i_{2m_0,n_0-1}\right) \\ y^2 = H^{c_2}_{2m_0+1,n_0}\left(a_{2m_0+1,n_0} + \mathrm{j}a^i_{2m_0+1,n_0}\right) \end{cases} \quad (9)$$

The interference in $\Omega^{*}_{\Delta 1,\Delta 1}$ can be eliminated.

After (8),the PLC channel is still or change little between the adjacent symbols, so that you can get more accurate channel estimation value, which could greatly eliminate the interference caused by the imaginary part of the channel estimation .Channel estimation is:

$$H = H^{c_1}_{2m_0,n_0-1} + H^{c_2}_{2m_0+1,n_0} \quad (10)$$

IV. SIMULATION RESULTS

In the simulation, it was used four static paths, which had been mentioned in the PLC [12]. Channel state and the main system parameters are as follows:

TABLE I. SIMULATION PARAMETER SETTINGS

Sampling frequency	100KHz，
Data Format	N = 256,40 symbol, A total of 40
Multipath power	0,-3,-10,-13
Path delay	0,2,4,8（Sampling interval）
Mapping	QPSK,OQPSK,CP=20samples
Doppler shift	0Hz,0.1Hz,1Hz

In the simulation, the OFDM/OQAM pulse function was used to the IOTA whose duration was $4T_0$, so the total length was $L = 4M = 1024$.

The OFDM/OQAM and OFDM/CP was used to LS (Least Squares, LS) channel estimation and ZF (Zero forcing, ZF) channel equalization methods.
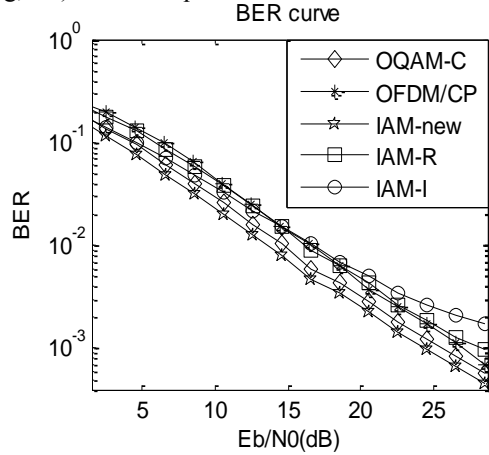

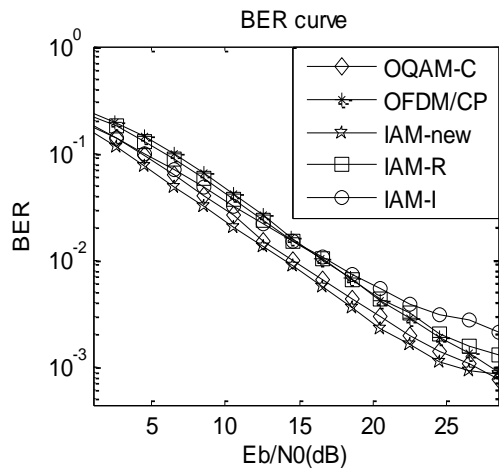Figure 5.   Results in PLC channel with no Doppler shift

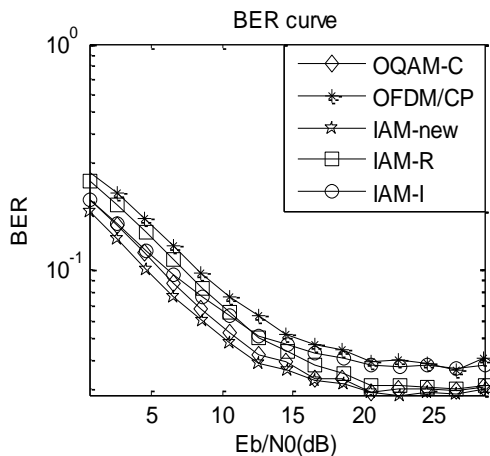Figure 6.   Results in PLC channel with Doppler shift 0.1 Hz

Figure 7.   Results in PLC channel with Doppler shift 1Hz

In the PLC channel, the situation where is no Doppler frequency shift in Fig .5, e.g., at a BER of 1.0×10^{-3}, IAM-new E_b / N_0 is a little better than OQAM-C, while OQAM-C has2 dB gain versus OFDM/CP which is better than

IAM-I,IAM-R due to the adjacent imaginary intrinsic interference.

When the Doppler frequency shift is 0.1Hz in Fig .6, e.g., at a BER of 1.0×10^{-3}, OQAM-C E_b / N_0 has 4dB gain versus IAM-R and nearly 2dB gain versus OFDM/CP, IAM-new is little better than OQAM-C. Due to the imaginary intrinsic interference, IAM-R and IAM-I are worse than OFDM/CP.

When the Doppler frequency shift is 1Hz in Fig .7, OFDM/CP is sensitive to the Doppler frequency shift, so it soon reaches the error floor and has a poor performance than IAM-R，IAM-I, OQAM-C.OQAM-C can finally achieve the same error floor as IAM-new. As OQAM-C is designed by the interference cancellation, while the IAM-new is the pilot power based on the maximum, at the beginning, the BER performance of IAM-new is better than OQAM-C, however, as the increasing of E_b / N_0 ,their performance is almost the same.

V. CONCLUSION

The simulation results show that OQAM-C bit error performance is almost the same as the IAM-new but better than the IAM-R, IAM-I, OFDM/CP. As Doppler shift increasing, OFDM/CP soon reaches the error floor, while OFDM/OQAM gets the better result. Moreover, the sparse pilot design approach can effectively reduce the pilot peak power compared to the IAM-R, IAM-I, IAM-new.

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