Modulation Format Recognition in Visible Light Communications Based on Higher Order Statistics

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***Abstract*—In this paper, modulation formats of M-ary pulse amplitude modulation (PAM)- and M-ary quadrature amplitude modulation (QAM)- asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM) could be recognized autonomously in visible light communication (VLC) systems, by using higher order statistics (HOS). Fourth-order cumulants are applied as the decision criterion and the HOS method's correct decision probability is investigated by Monte-Carlo (MC) simulation.**

I. INTRODUCTION

Nowadays, visible light communications (VLC) has become a promising technology that implements communication and illumination simultaneously by using light-emitting diodes (LEDs) [1], [2]. Being considered as a potential candidate for 5G wireless communications, the VLC system is with many attractive advantages, such as low cost, high bandwidth, and being immune to radio frequency (RF) interference [3].

However, with the developing of telecommunications, the demand for data rate in terms of spectral efficiency is sharply increasing. The communication system will have to become more flexible, programmable and efficient to satisfy this huge incoming services requirement [4]. The modulation format recognition (MFR) is one of such important techniques to improve the system's spectral efficiency. Under this scheme, the modulation format is detected autonomously in order to demodulate the signal without any prior information, whilst the performance of signal processing algorithm is also improved [4]. The performance of higher order statistics (HOS)-based MFR in VLC system is investigated in the paper, where four modulation formats are recognized, including 4-pulse amplitude modulation (PAM), 16-PAM, 4-quadrature amplitude modulation (QAM) and 16-QAM asymmetrically clipped optical (ACO)-orthogonal frequency division multiplexing (OFDM), respectively.

The rest of the paper is organized as follows. Section II presents the theory of ACO-OFDM and HOS. The simulation results are discussed in Section III. Section IV gives the concluding remarks to the whole work.

II. THEORY

The asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM) scheme is applied to improve the peak-to-average power ratio (PAPR) performance of conventional OFDM signal $x[n]$. In such a scheme, only the odd subcarriers are modulated, and the negative samples in time domain could be clipped without loss of information. Therefore, without consideration of noise, the ACO-OFDM signal $y[n]$ is given by [5]

$$y[n] = \frac{1}{2}\left(x[n] + |x[n]|\right). \tag{1}$$

After passing through the photo-detector (PD), the fourth-order cumulants of the received signal ACO-OFDM signal $y[n]$ are used for modulation format classification. The estimates of fourth-order cumulants are given by [6]

$$\hat{C}_{40} = \frac{1}{N}\sum_{n=0}^{N-1} y^4[n] - 3\hat{C}_{20}^2, \tag{2}$$

$$\hat{C}_{41} = \frac{1}{N}\sum_{n=0}^{N-1} y^3[n]\, y^*[n] - 3\hat{C}_{20}\hat{C}_{21}, \tag{3}$$

$$\hat{C}_{42} = \frac{1}{N}\sum_{n=0}^{N-1} |y[n]|^4 - \left|\hat{C}_{20}\right|^2 - 2\hat{C}_{21}^2, \tag{4}$$

where $\hat{C}_{20}$ and $\hat{C}_{21}$ are the estimates of second-order moments. $\hat{C}_{20}$ and $\hat{C}_{21}$ are given by [6]

$$\hat{C}_{20} = \frac{1}{N}\sum_{n=0}^{N-1} y^2[n], \tag{5}$$

$$\hat{C}_{21} = \frac{1}{N}\sum_{n=0}^{N-1} |y[n]|^2. \tag{6}$$

When the normalized fourth-order cumulants are employed and the noise is considered, the fourth-order cumulants are modified as follows [4]

$$\tilde{C}_{4i} = \frac{\hat{C}_{4i}}{\left(\hat{C}_{21} - \hat{C}_{21,g}\right)^2}, \tag{7}$$

where i is the index of fourth-order cumulant ($i = 0, 1, 2$), and $\hat{C}_{21,g}$ is the estimate of the additive noise's variance.

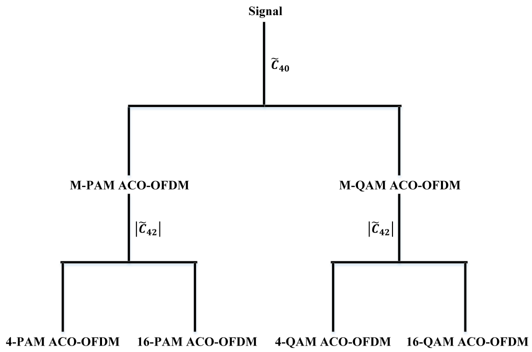

Fig. 1. Hierarchical classification scheme based on HOS in VLC systems.

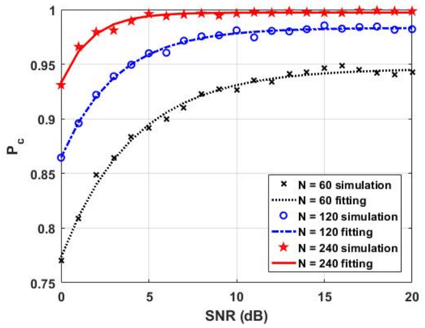

Fig. 2. The P_{c} on classification between 16-PAM and 16-QAM ACO-OFDM in the presence of Gaussian noise.

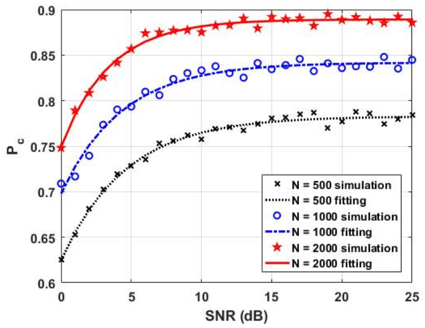

Fig. 3. The P_{c} on classification among 4-PAM, 16-PAM, 4-QAM and 16-QAM ACO-OFDM in the presence of Gaussian noise.

III. SIMULATION AND DISCUSSION

According to the fourth-order cumulants, M-ary PAM ACO-OFDM and M-ary QAM ACO-OFDM signals could be distinguished as shown in Fig. 1, where four modulation formats are classified by using fourth-order cumulants, including 4-PAM, 16-PAM, 4-QAM and 16-QAM ACO-OFDM. The variances of the fourth-order cumulants for a certain modulation format are changed as the signal-to-noise ratio (SNR) varies, whilst their means are unaffected. So the optimal thresholds for classification can be obtained based on the means of fourth-order cumulants [7], In the simulation, 1000 Monte-Carlo (MC) trials are carried out to calculate the probability of correct decision for each modulation format.

In the presence of Gaussian noise, performance of correct decision probability between 16-PAM ACO-OFDM and 16-QAM ACO-OFDM is shown in Fig. 2, where P_{c} is the probability of correct classification, which is the ratio of correct classification number to the number of whole MC trials–1000; whilst N denotes the number of incoming signal that is required for classification. Fig. 2 depicts that P_{c} increases as the number N of incoming signal and SNR becomes larger. It will reach the steady state when SNR is larger than 15 dB. The corresponding P_{c} of MFR is larger than 0.997, and the incoming signal's number is 240. When SNR is smaller than 5 dB, the correct decision probability declines rapidly as the SNR decreases.

The performance of MFR among 4-PAM, 16-PAM, 4-QAM and 16-QAM ACO-OFDM is also investigated. Fig. 3 depicts the correct decision probability P_{c} under various SNR for the four modulation formats. Compared with that in Fig. 2, the correct decision probability P_{c} is decreased, since the cumulants difference of similar formats are smaller. The P_{c} increases as the SNR grows, and reaches an peak value with SNR of 15 dB. In the steady state, P_{c}s are 0.782, 0.841 and 0.889, when the numbers of incoming signal are 500, 1000 and 2000, respectively. Therefore, the number of incoming signal N can be even larger to decrease the decision error further.

IV. CONCLUSION

In this paper, the HOS scheme has been demonstrated to realize the MFR among 4-PAM, 16-PAM, 4-QAM and 16-QAM ACO-OFDM in VLC system. The method employes the fourth-order cumulants as decision criterion. The correct decision probability is investigated by using MC simulation. The results show that the HOS can achieve high accuracy for MFR with proper parameters.

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