

Enhanced Blind Modulation Formats Recognition using Connected Component Analysis with Quadruple Rotation

Tianwai Bo, Jin Tang, Calvin Chun-Kit Chan

Department of Information Engineering, The Chinese University of Hong Kong
tianwai@ie.cuhk.edu.hk

Abstract: An enhanced algorithm is proposed to improve the recognition accuracy of connected component analysis based modulation formats recognition method. It alleviates the requirements for both the optical signal-to-noise ratio and number of points simultaneously.

Keywords: Modulation format recognition; Software-defined network

I. INTRODUCTION

Recently, management of optical networks is progressing more flexible and software-defined. Fully programmable bandwidth variable transponders are adaptive to the data rate and the modulation format, based on the transmission length and channel state information so as to increase the spectral efficiency and assure the quality of service. In particular, it is highly desirable for the receivers to have the cognitive ability of the signal's modulation format, hence proper digital signal processing (DSP) algorithm can be applied to achieve the optimum performance for the received optical signal. Another application that requires modulation format recognition (MFR) is the coherent burst mode transmission system, in which the coherent receiver is required to respond to the fast channel switching.

Several MFR schemes have been proposed, recently. It can be classified into Jones space method [1] and Stokes space methods based on the domain, where the MFR is performed. In general, Stokes space is intrinsically insensitive to laser phase noise and frequency. In [2, 3], K-means and other machine learning methods have been used to identify the modulation formats. However, the computation-extensive iterative operations hinder their practical implementation. In [4], we have proposed a novel blind MFR method based on image processing technique, in which connected component analysis (CCA) has been used to count the number of constellation points in the converted binary graph from the received symbols in Stokes space. It provides a one-step recognition of modulation formats other than iterative approaches. In this paper, we propose an enhanced blind MFR method based on our previous work. We show that the requirements for both optical signal-to-noise ratio (OSNR) and number of points can be significantly reduced, with only slight additional simple logic operations, making the MFR algorithm more robust for practical use.

II. PRINCIPLES

At the coherent receiver, it is common to perform analog-to-digital conversion, chromatic dispersion compensation and timing recovery, before handling the modulation format. After these pre-processing, in our proposed blind modulation recognition scheme, the dual polarization signal is first converted to the Stokes space, by [3]

$$[s_1, s_2, s_3] = [|X|^2 - |Y|^2, 2\text{Re}\{X \cdot Y^*\}, 2\text{Im}\{X \cdot Y^*\}] \quad (1)$$

where X and Y represent the two orthogonal polarizations, while $\text{Re}\{\cdot\}$ and $\text{Im}\{\cdot\}$ stand for the real and the imaginary parts of a complex number, respectively. It can be easily seen that the absolute phase information has been removed in the transformation, i.e., the laser frequency offset and phase noise have no effect in the Stokes space. Another information that can be concluded from (1) is that phase-shift-keying (PSK) signals are distributed in the s_2 - s_3 plane only as $s_1=0$, while the distribution of quadrature-amplitude-modulation (QAM) signals like 8QAM and 16QAM in Stokes space are more complicated and distributed in the planes that are parallel to s_0 -plane, as depicted in Fig. 1.

Then, similar processes are performed as those in our previous work. First, the random-walked polarization should be tracked, which needs only several hundreds of points as demonstrated in [5]. Secondly, the points after normalization satisfying the constraints, as listed in Table I, are projected onto the s_2 - s_3 plane. Then a density filter based on Voronoi density estimation is applied to remove the points with normalized density smaller than the threshold Th . After these DSP procedures, we convert the survived points to a binary graph, with a pre-defined resolution N , after which an averaging filter is used to smooth the image. Finally, the connected component analysis is employed to count the number of constellation points. It traverses each pixel with value "1" in the graph and checks whether it is connected to any of the surrounding 8 pixels. After labelling all the subsets, the number of subsets is obtained, obviously. The modulation format recognition is achieved based on the number of subsets. The detailed algorithm description could be found in [4].

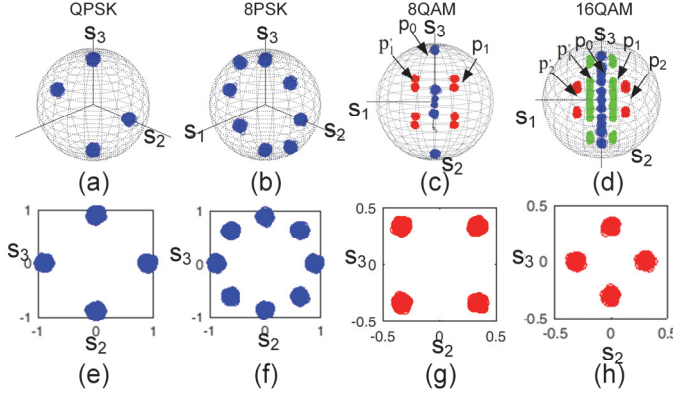


Fig. 1 Signal representations in Stokes space for (a) QPSK, (b) 8PSK, (c) 8QAM, (d) 16QAM (e)-(h) are the projections on the plane of s_2 - s_3 plane.

TABLE I
CONSTRAINTS OF POINTS FOR PROJECTION
OF DIFFERENT MODULATION FORMATS IN
STOKES SPACE

Modulation Formats	Constraints of Points for Projection
QPSK	$ s_I < 0.1$
8PSK	$ s_I < 0.1$
8-QAM	$0.3 < s_I < 0.4$
16-QAM	$ s_I > 0.4$

Now, we investigate how to alleviate the requirement of OSNR for the CCA-based MFR method. In principle, the parameter, which is the most relevant to OSNR sensitivity, is the threshold Th in the density filter. It is intuitive that increasing Th results in increasing the OSNR sensitivity, as it removes more data samples which are corrupted by the noise. Fig 2(b) shows the converted binary graph from a set of PM-8PSK signal (SNR = 12 dB) with the threshold equal to 0.65 in the density filter. As the noise level is high, all the subsets in the converted binary graph mix together and CCA could not figure out the correct number of subsets. However, simply increasing Th leads to less survived points after the density filtering, which probably makes the subsequent CCA algorithm fail. In Fig.2 (c), the threshold in the density filter is set to be 0.8. It can be seen that even though the subsets can be distinguished now, there are two subsets missing, such that the output of CCA is still not correct. Fortunately, we can take advantage of the symmetry property of the patterns of these modulation formats in the binary graph, as shown in Fig. 1, and use simple logic AND between the original binary graph and the rotated graph to make up for the missing subsets. It is worth noting that the logic AND is employed in the binary graph, which is quite computation efficient in the DSP circuit. The additional logic operations are nearly negligible compared with the processing of complex numbers in other parts of the algorithm. Here, we name the modified CCA-based algorithm as CCA-QR, in which QR is the short form for quadruple rotation, as in

$$I = I \& \text{rot}_{\pi/2}(I) \& \text{rot}_{\pi}(I) \& \text{rot}_{3\pi/2}(I) \quad (2)$$

where I is the 0-1 matrix of the binary graph, $\&$ is the AND operation, and rot_{θ} is the function that rotates the matrix by an angle of θ . Fig. 2(d) shows the binary image after the QR process of Fig. 2(c). The output of CCA is correct now for recognition.

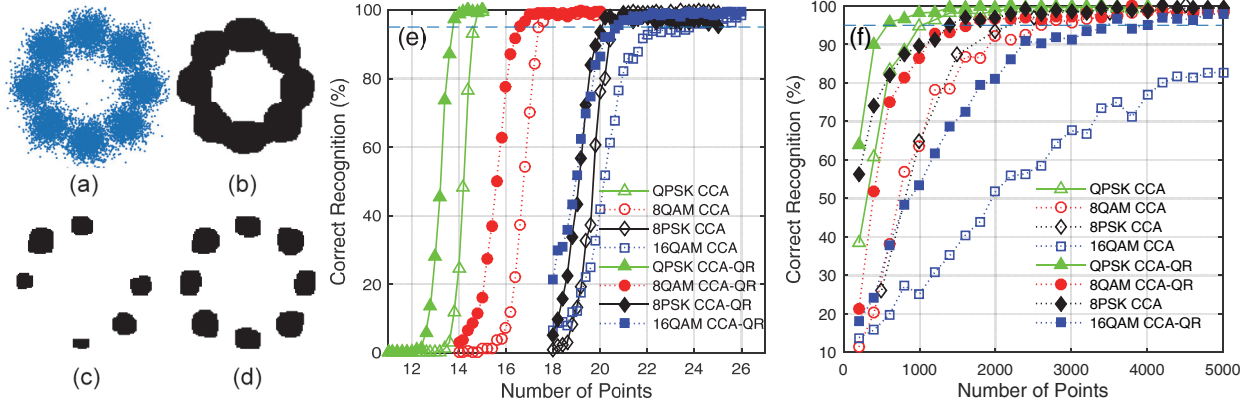


Fig. 2 (a) Constellation of 8PSK signal, SNR = 12; (b) Converted binary image, $Th = 0.65$; (c) Converted binary image, $Th = 0.8$; (d) Converted binary image, $Th = 0.8$, with quadruple rotation; (e) & (f) Simulation results of the correct recognition rate under different OSNR values and different number of points.

III. NUMERICAL SIMULATION

We have performed numerical simulations for the proposed MFR scheme. 32-Gbaud PM-QPSK, PM-8QAM, PM-8PSK and PM-16QAM signal were generated and passed through a channel with additive Gaussian white noise. The converted binary image had a size of 100×100 pixels ($N = 100$). The threshold for the Voronoi filtering was set to be 0.65 and 0.8, respectively, corresponding to our previous CCA-based method and the newly proposed CCA-QR method. First, the OSNR value was varied from 10 dB to 26 dB, with a step of 0.2 dB, each having 500 independent implementations. The correct recognition rate was then calculated. Fig. 2(e) and (f) show the correct recognition rate under different OSNR values, and different number of points involved in the MFR. The OSNR, in the latter case, was set to be 15 dB, 18 dB, 22 dB, and 24 dB for QPSK, 8QAM, 8PSK and 16QAM, respectively. The increase of OSNR sensitivity was clearly seen in Fig. 2(e), i.e., ~ 1 dB for QPSK, 8PSK and 8QAM, and ~ 2 dB for 16QAM. Meanwhile,

for each tested modulation formats, the number of required points to successfully recognize the modulation formats was reduced significantly, as depicted in Fig. 2(f). The case of 16QAM showed the most significant improvement, which only about half of the points (5000) are needed to reach a successful rate of 95%, compared with the previous scheme (~10000).

IV. EXPERIMENTAL RESULTS

The experimental setup and configurations were the same as those in [4]. 32-Gbaud polarization-multiplexed QPSK and 16QAM signals were transmitted in a general coherent optical communication testbed. Fig. 3(a) shows the experimental setup and the major DSP processes. CCA-based and CCA-QR-based MFR methods were employed to recognize the modulation formats of the received signal, with threshold $Th = 0.65$ and 0.8 , respectively. Fig 3 (b) shows the back-to-back bit error rate (BER) performance. The orange and yellow color blocks represented the successful recognition range of the CCA and CCA-QR based MFR method. The OSNR sensitivity was increased by 1.2 dB and 4.3 dB for QPSK and 16QAM, respectively. Fig. 3(c)-(n) show the converted binary graphs of the CCA and CCA-QR based method. The performance improvement of CCA-QR was significant, as shown in Fig. 3(c) & (i), and (f) & (l).

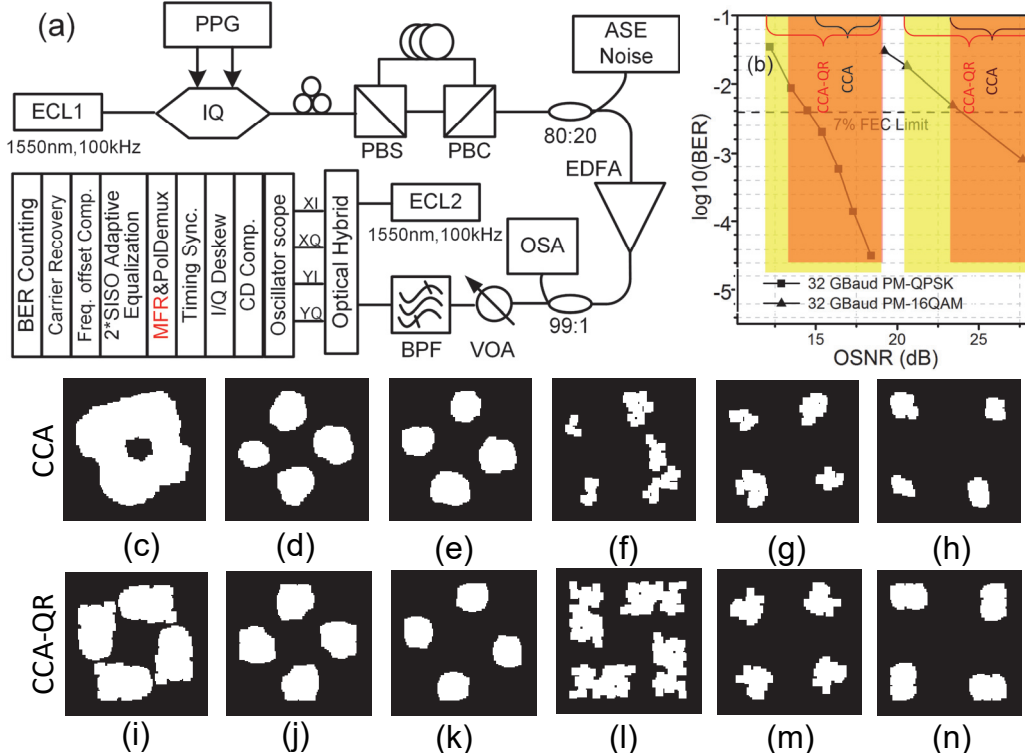


Fig. 3 (a) Experimental setup; (b) back-to-back BER result; (c)-(e) converted binary graph of QPSK signals using CCA, OSNR = 12.2 dB, 13.5 dB, and 14.5 dB, respectively; (f)-(h) converted binary graph of 16QAM signals using CCA, OSNR = 20.6 dB, 23.4 dB and 27.7 dB, respectively; (i)-(n): the corresponding CCA-QR results.

V. SUMMARY

We have proposed a modified modulation format recognition method based on image processing techniques. It shows that, via both simulation and experiment, about 1~3 dB OSNR sensitivity is improved, for coherent polarization multiplexed PSK and QAM signals, with requiring slight additional simple logic operations.

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