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Digital Signal Processing Based Laser Phase Noise Compensation at Coherent Optical Quadrature Phase-Shift Keying Receiver Using K-means Clustering and Viterbi-Viterbi Method Jointly

[1]Nitish Sinha and [2]Bishanka Brata Bhowmik
Department of Electronics & Communication Engineering, Tripura University
E-mail: [1]nitish.ns0176@gmail.com, [2]bishankabhowmik@tripurauniv.in

ABSTRACT

In this paper, we have proposed a technique to compensate the laser phase noise in a coherent optical system quadrature phase-shift keying modulation using the combination of K-means Clustering and Viterbi-Viterbi algorithm at the receiver. Results are compared to use the K-means Clustering and Viterbi-Viterbi to alleviate the noisy signal.

Keywords: *Quadrature Phase Shift Keying, Digital Signal Processing, Laser Phase Noise, Viterbi-Viterbi algorithm, K-means clustering*

1. INTRODUCTION

For the last few decades, optical fiber communication got very much attention for the long haul and high data rate communication. It's partly because of the low loss in optical fiber[1] and also as optical fiber support enormous bandwidth[2] different types of fiber induced linear and nonlinear noise namely phase noise, chromatic dispersion, nonlinearity effect like Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM), Four-Wave Mixing (FWM). To demodulate the transmitted signal incoherent communication coherent receiver is used. In the coherent receiver[3], a laser can be found which basically works as a local oscillator (LO) and ideally it should be in coherence with the transmitter's laser. In this case, the receiver side local oscillator laser light phase will be not the same as transmitter LO. Because at the same time the movement of two independent lasers from higher energy level to lower energy level is not possible. So some phase noise will be received in receiver photodiode [4, 5]. Fig.1(a) illustrates as an ideal case clock signal but practically it is not possible. Fig1(b) shows that the actual signal time period T is not constant, where clock frequency f=1/T, thereby rise time and fall time is varied. So real-world clock signal time period varies namely T0, T1, T2 ...

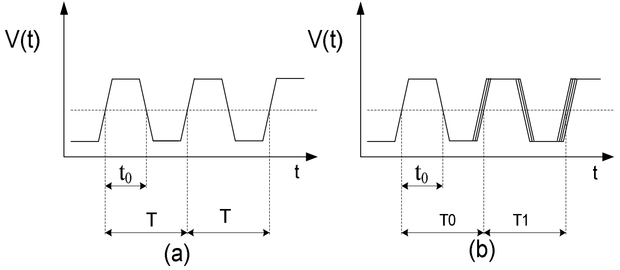


Figure.1 (a) Ideal Clock Signal. (b) Actual Clock Signal (t is the time scale)

In the fig. 2(a) and 2(b) the ideal clock which is without noise and actual clock signal with which is with noise have been shown in frequency domain respectively.

For ideal signal:

$$V(t) = A \sin(2\pi \nu t) \quad (1)$$

Where
A = nominal amplitude
ν = nominal frequency

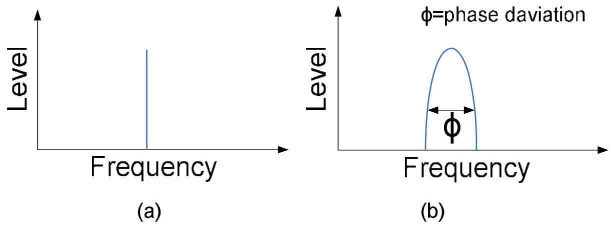


Figure 2.(a) Ideal Clock Frequency Domain (b) Actual clock frequency domain.

For real signal

$$V(t) = \{A + E(t)\}\sin(2 + \varphi(t))) \quad (2)$$

Where
E(t) = Amplitude fluctuation
Φ(t) = Phase fluctuation

Phase Noise is Unintentional phase modulation on a carrier. This φ(t) is called phase noise.

- **Laser Phase Noise**

The laser output of the signal frequency is not constant but frequency change randomly. The output of the laser the transmitter is [6]

$$q_T(t) = A_T s(t)\exp\{-i[2\pi f_c t - \phi(t)]\} \quad (3)$$

Where, s (t) is the output of laser or data, f_c is the laser center frequency and φ(t) is the laser phase noise. The instantaneous frequency deviation is

$$f_i = -\frac{1}{2\pi}\frac{d\varphi}{dt} \quad (4)$$

Instantaneous frequency deviation is zero then φ(t) is Gaussian noise σ_f

$$\Phi(t) = \phi(t_0) - 2\pi\int f_i(\tau)d\tau \quad (5)$$

In this paper, we have compensated laser phase noise jointly using K-means Clustering and Viterbi-Viterbi algorithm.

- **Laser Phase Estimation and Compensation**

K-means Clustering Algorithm: The DSP technique, K-means clustering algorithm is used to design the different modulation formats and to measure this centroid position [7]. We simulated a QPSK modulation signal and measured the four centers of the constellation points of modulation signal along with phase noise. The constellation diagram of the modulation signal has been shown in the fig:3, where the spreading of the constellation points can be seen in presence of phase noise.

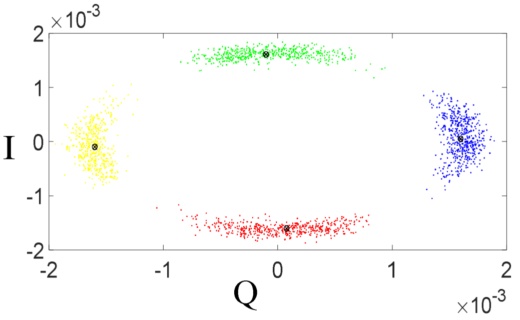


Figure 3.Constellation diagram with phase-noise

The K-means clustering algorithm center all nearest or neighboring points into four centers to make four cluster of the QPSK system

- **Method of k-means clustering:**
  - ➢ First select 2D-vector from data samples [x(1),x(2),…,x(N)]
  - ➢ Initialize cluster centroids u_k from the N data samples.
  - ➢ Represent Xi in the complex I/Q plane.
  - ➢ Calculate distance di between xi and each cluster centroid u_k.
  - ➢ Choose the minimum distance d= min{di}.
  - ➢ Assign xi to the nearest cluster.
  - ➢ Update the Cluster center of the winner cluster by calculating the mean.
  - ➢ Store the u_k cluster centroids. [8]

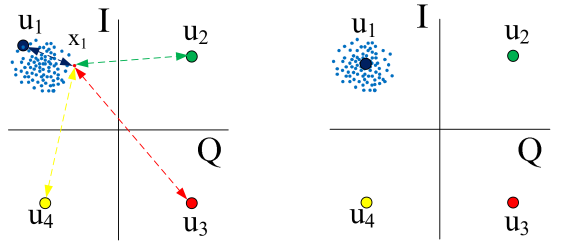


Figure 4.(a) k-means shortest distance measure. (b)Update the centroid cluster 1.

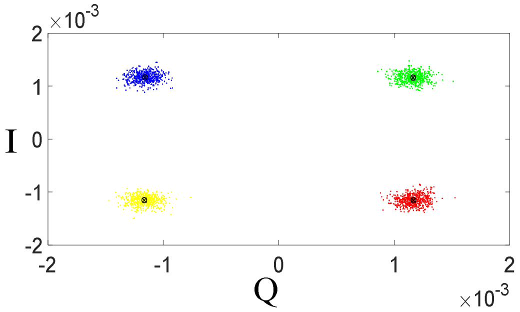


Figure 5.QPSK signals have four phase-states

As shown in Fig.5 since QPSK signals have four phase-states, four clusters of data points are found.

- **Viterbi-Viterbi algorithm:**

The bandwidth of the transmitter and receiver local oscillator ranges from10 kHz to 10 MHz and the symbol rate is 10 G-symbol/s so the phase modulation is better than the symbol phase varies. The laser phase estimation and compensation technique known as block phase noise estimation. The block diagram of the phase estimation technique is shown below the fig.6. [9]

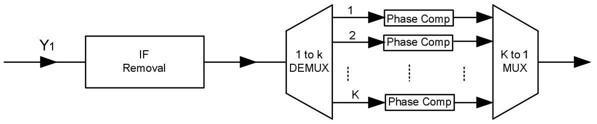


Figure 6. Block diagram of an IF and phase compensation.

Here we discuss the block phase noise estimation it's also called the Viterbi-Viterbi algorithm. After finding the centroid position using K-means clustering we apply the Viterbi-Viterbi algorithm.

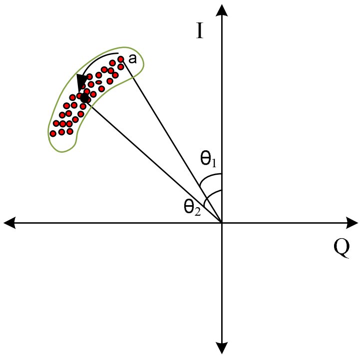
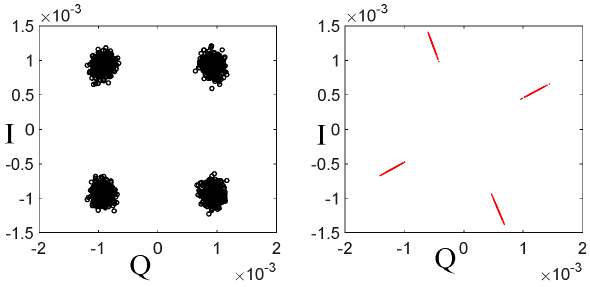


Figure 7. Phase Compensation technique using Viterbi-Viterbi.

A particular point 'a' phase is θ_1 and this particular cluster center point phase is θ_2. So the phase scatter is (θ_2-θ_1). And this particular point phase will be compensated.



(a) (b)

Figure 8.(a) Constellation diagram after Viterbi-Viterbi algorithm is used (b) Constellation diagram after K-means and Viterbi-Viterbi jointly used.

The fig.8 (a) shows a constellation diagram of compensation of phase noise using the Viterbi-Viterbi algorithm and here present of phase noise can be still observed. The fig.8 (b) shows the constellation diagram of phase compensation jointly used k-means clustering and Viterbi-Viterbi algorithm, where it can be seen that the phase noise has been extensively minimized.

CONCLUSION

In this paper, we propose for the first a joint algorithm using K-means clustering and Viterbi-Viterbi method to compensate for the laser phase noise in a coherent optical communication system. It has been also shown in the result section (fig.8). Our proposed method shown a better result than the method here Viterbi-Viterbi algorithm is used only.

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AUTHOR PROFILES

Mr. Nitish Sinha pursued a Bachelor of Engineering in Electronics and Communication Engineering from Tripura Institute of Technology, Tripura in 2018. He is currently pursuing Master of Technology in Electronics and Communication Engineering from Tripura University (A central university), Tripura since 2018.

Dr. Bishanka Brata Bhowmik is currently working as an Assistant Professor in the Department of Electronics and Communication Engineering at Tripura University (A central university), Tripura. His main research interests are Optical fiber Communication & Photonics.