Assignment3

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December 5, 2022

Abstract

This is a demo file for the assignment3, not a standard academic paper. Contents of the paper include some related knowledge in my field, which is copied from others' published papers.

1 Introduction

Continuous-variable quantum key distribution (CV-QKD) enables information-theoretically secure key exchange between two parties using the continuous-variable properties of the quantised electromagnetic light field. The quantum information used for generating the secret key can be imprinted onto coherent states in the amplitude and phase quadratures of laser light using electro-optical modulators at the transmitter. These quantum states are transmitted through an insecure channel typically assumed to be fully controlled by an adversary and measured by some form of coherent detection, e.g. radio-frequency heterodyne or phase-diverse homodyne detection at the reciever. The use of technology quite similar to that employed in classical coherent telecommunications is an attractive feature of CV-QKD with respect to integrability in existing telecom networks.

Here, we present a machine learning framework based on Bayesian inference, implementing an unscented Kalman filter (UKF) to estimate the phase of a pilot tone. The UKF is an adaptive estimation algorithm capable of adjusting itself according to the differences between the estimated model and the measured system. The UKF's performance is investigated experimentally in a Gaussian-modulated CV-QKD protocol operating over a 20 km fibre link using first nominally <100 Hz linewidth lasers and then substituting a standard telecommunications laser (≈10 kHz) at the transmitter. The UKF achieves exceptional performance compared to a standard reference method and the extended Kalman filter with excess noise figures below 1% shot noise variance for a wide range of pilot tone SNRs. For instance, with the low linewidth laser, the UKF performs consistently well down to 3.5 dB pilot tone SNR (SNR_{pilot}), which considerably relaxes the constraints on the filtering bandwidth. The UKF therefore not only enables higher secret key rates but also promises a more robust CV-QKD system with regards to environmental factors that may deteriorate SNR_{pilot}. Moreover, it enables secret key generation using systems that would otherwise be unable to do so using the reference method.

2 METHODS

2.1 Machine learning aided phase tracked algorithm for carrier recovery

The phase noise associated with a time-varying pilot signal $y(t)$ acquired by a radio-frequency heterodyne receiver at discrete time instants $t = t_k$ can be corrected by evaluating

$$\theta_k \equiv \theta(t_k) = tan^{-1}(\frac{\mathcal{H}(y(k))}{y(k)}) \tag{1}$$

where $\mathcal{H}$ denotes the Hilbert transform. The linear trend in θ_k is removed to compensate for the frequency offset of the pilot tone leaving the phase noise. This method is standard for extracting the phase from a pilot signal and is equivalent to calculating the frequency offset, frequency shifting the pilot to baseband and then taking its argument, see Fig.1a. In coherent detection systems the additive noise caused by the beating of the LO laser with vacuum fluctuations within the measurement bandwidth limit the efficacy of this method, in addition to electronic noise. In principle, this can be solved by increasing the pilot signal power, however, as previously mentioned, this may be undesirable in a practical CV-QKD system.[1].

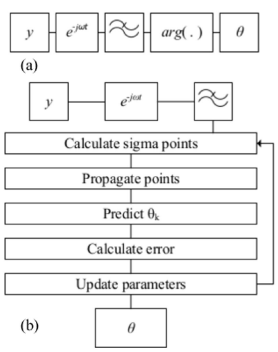

Figure 1: Two phase estimation algorithms. a. Reference method. b. machine learning approach.

References

[1] Hou-Man Chin, Nitin Jain, Darko Zibar, Ulrik L Andersen, and Tobias Gehring. Machine learning aided carrier recovery in continuous-variable quantum key distribution. *npj Quantum Information*, 7(1):1–6, 2021.