Practical phase noise model for continuous variable quantum key distribution with a real local oscillator

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Abstract

We have developed a practical phase noise model for continuous-variable quantum key distribution with a local local oscillator (LLO CV-QKD) protocols, in which part of the phase-reference measurement noise that can be locally calibrated by Bob at the receiver side is considered to be trusted. We show that the secure key rate and transmission distance of the LLO CV-QKD under the practical phase noise is significantly improved in comparison to that under the conventional phase noise model. We show that the secure key rate at the transmission distance of 25 km is improved more than 65% and the maxim transmission distance is increased more than 70% with some typical simulation parameters.

Introduction

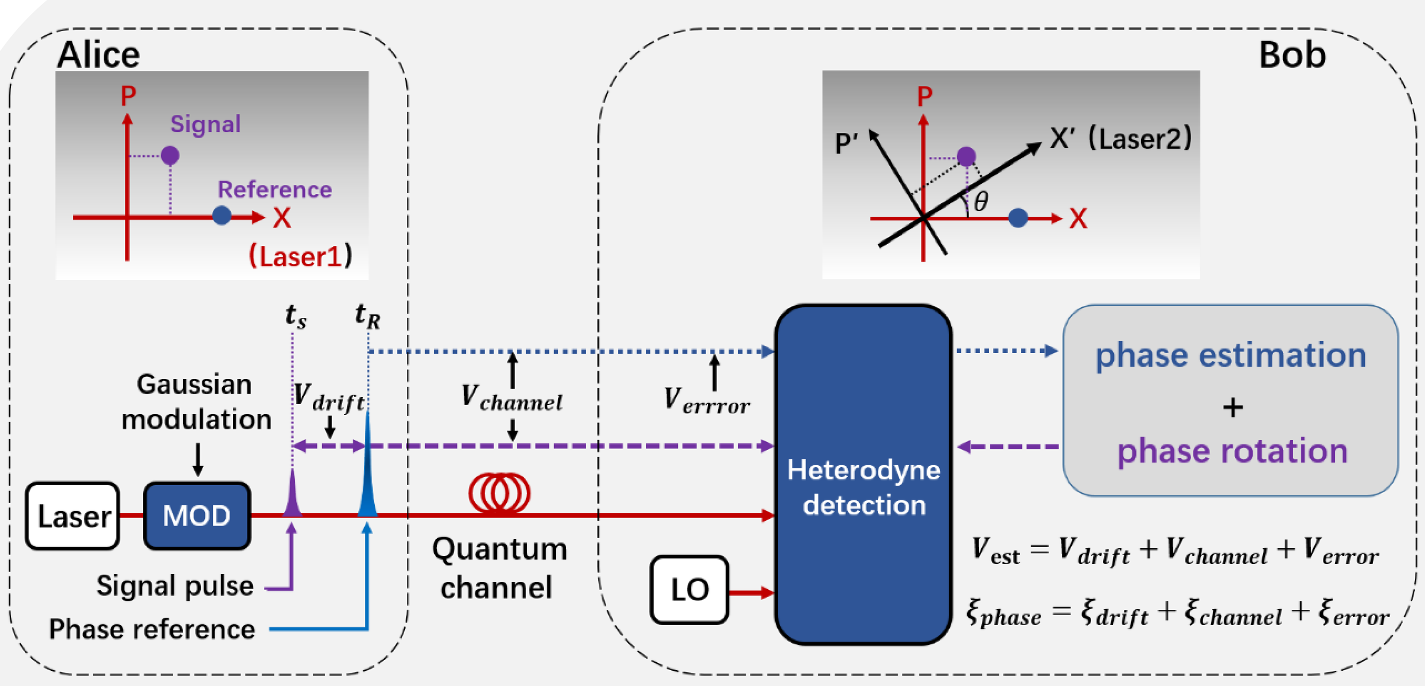

Fig. 1 LLO CV-QKD scheme and its phase compensation process.

In LLO CV-QKD, the weak quantum signal and the strong local oscillator (LO) are generated from two independent lasers at the sender and the receiver, respectively. The phase noise after phase compensation mainly consists of three parts: the relative phase drift noise ξ_{drift}, the relative phase accumulated noise $\xi_{channel}$, and the phase-reference measurement error ξ_{error}. Conventionally, the entire phase noise is regarded as untrusted noise, which pessimistically estimates the key rate. In recent refined phase noise model, the phase-reference measurement noise is considered trusted, which overestimates the trusted part of the phase noise, and rending an optimistic overestimation of the key rate. Therefore, a refined phase noise model is needed to describe the phase noise in the LLO CV-QKD.

Conventional phase noise model & practical phase noise model

Conventional phase noise model

$$\xi_{tot} = \xi_0 + \xi_{AM} + \xi_{LE} + \xi_{ADC} + \xi_{phase}$$

$$\xi_{rest} = \xi_{AM} + \xi_{LE} + \xi_{ADC}$$

$$\xi_{phase} = \xi_{drift} + \xi_{channel} + \xi_{error}$$

$$\chi_{line} = \frac{1}{T} - 1 + \xi_{tot}$$

$$\xi_{het} = \frac{2 - \eta + 2\nu_{el}}{\eta}$$

Practical phase noise model

$$\xi_{error} = V_A \frac{(\chi + 1)}{E_R^2}, \chi = \frac{1 - T}{T} + \varepsilon_0 + \frac{2 - \eta + 2\nu_{el}}{\eta}$$

$$\chi = \chi^u + \frac{\chi^T}{T}, \chi^u = \frac{1 - T}{T} + \varepsilon_0, \chi^T = \frac{2 - \eta + 2\nu_{el}}{\eta}$$

$$\xi_{error}^u = V_A \left(\frac{\chi^u + 1}{E_R^2}\right), \xi_{error}^T = V_A \left(\frac{\chi^T}{E_R^2}\right)$$

$$\chi_{line}^T = \frac{1}{T} - 1 + \xi_{tot}^T, \xi_{tot}^T = \xi_{tot} - \frac{\xi_{error}^T}{T}$$

$$\xi_{het}^T = \frac{2 - \eta + 2\nu_{el}}{\eta} + \xi_{error}^T$$

$$\chi_{tot} = \chi_{line} + \frac{\chi_{het}}{T} = \chi_{line}^T + \frac{\chi_{het}^T}{T} = \chi_{tot}^T$$

Calculations and numerical simulations

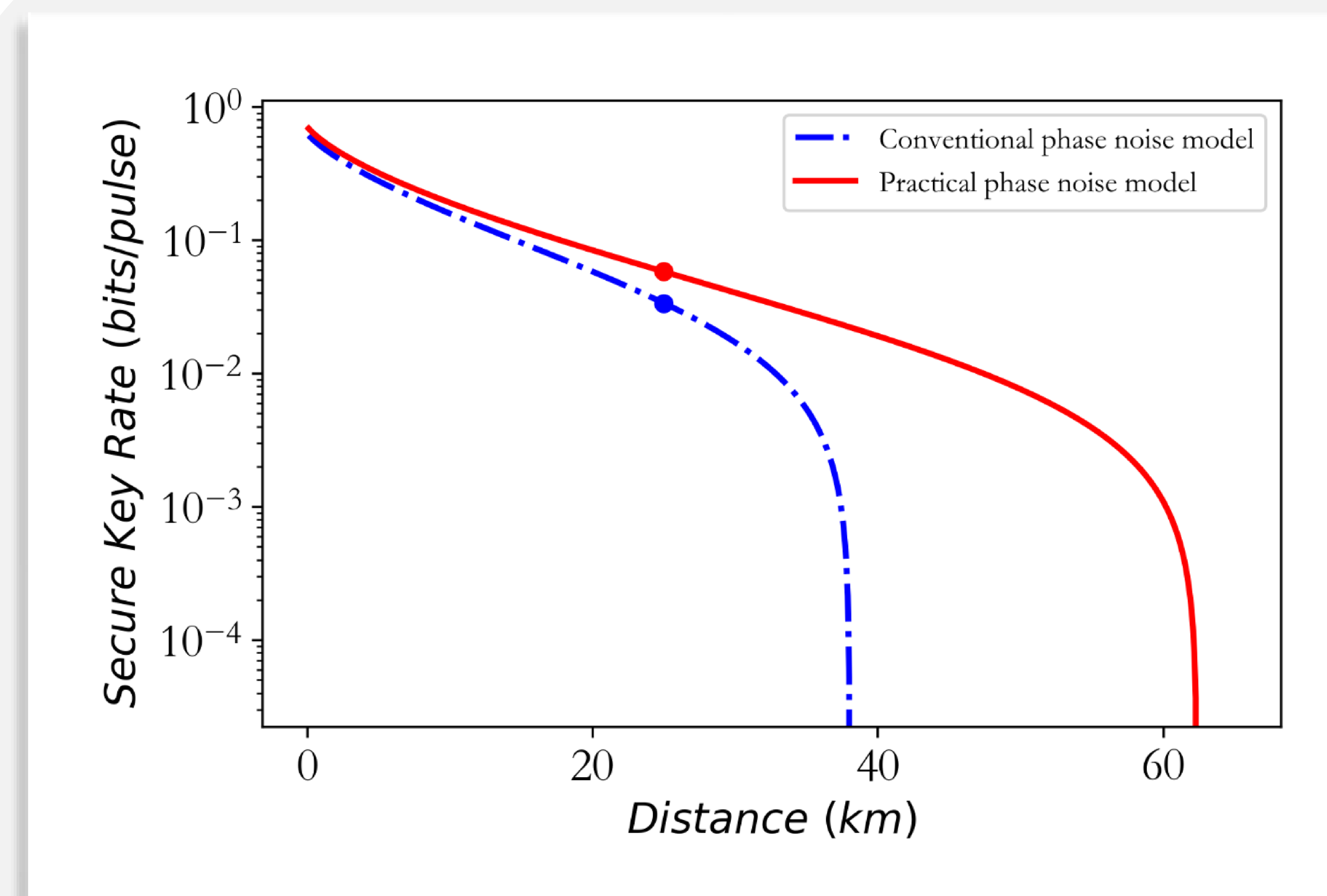

Fig. 2 Simulation results of secure key rate under the practical phase noise model (red solid line) and the conventional phase noise model (blue dash-dotted line) for the LLO CV-QKD system. The simulation parameters are $\xi_0 = 0.01, \nu_{el} = 0.1, \eta = 0.5, \beta = 95\%, d_{dB} = 40, R_e = 40\ dB, R_e = 30dB, E_R^2 = 1000$, $V_A = 40$, and the ADC quantization number n=10.

In Fig. 2, we show the simulation results of secure key rate for the time-polarization multiplexed LLO CV-QKD scheme based on heterodyne detection. For comparison, we present the results under the conventional phase noise model and the practical phase noise model. In the conventional phase noise model, the entire phase noise is regarded as untrusted noise. While in the practical phase noise model, part of the phase measurement noise with respect to the detector efficiency η and the detector electronic noise ν_{el}, as well as the phase-reference intensity E_R^2 on Bob's side is considered as trusted noise because which can be calibrated by Bob at the receiver side. The secure key rate at the transmission distance is increased more than 65%. The secret key rate at the transmission distance of 25 km optical fiber is increased more than 75.

Conclusion

We have established a practical phase noise model that can be applicable to current LLO CV-QKD protocols with phase reference. We show that the secure key rate and the transmission distance of the LLO CV-QKD system under the practical phase noise model is significantly improved in comparison to that under the conventional phase noise model.

Reference

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