Strengthening practical continuous-variable quantum key distribution against measurement angular error

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Introduction

Continuous-variable quantum key distribution (CV-QKD) provides a way for two remote participants called Alice and Bob to establish symmetric keys through an unsafe channel [1-2]. Experimental implementation of the CV-QKD systems using Gaussian-modulated coherent states (GMCS) has made significant progress recently [3]. At the mean time, a non-orthogonal measurement angular error between quadrature components X and P from heterodyne detection is always ignored in the current experimental scheme. In order to solve the problem, we propose a calibration and compensation method which can significantly help improve the performance of the practical CV-QKD systems.

Measurement angular error in practical CV-QKD

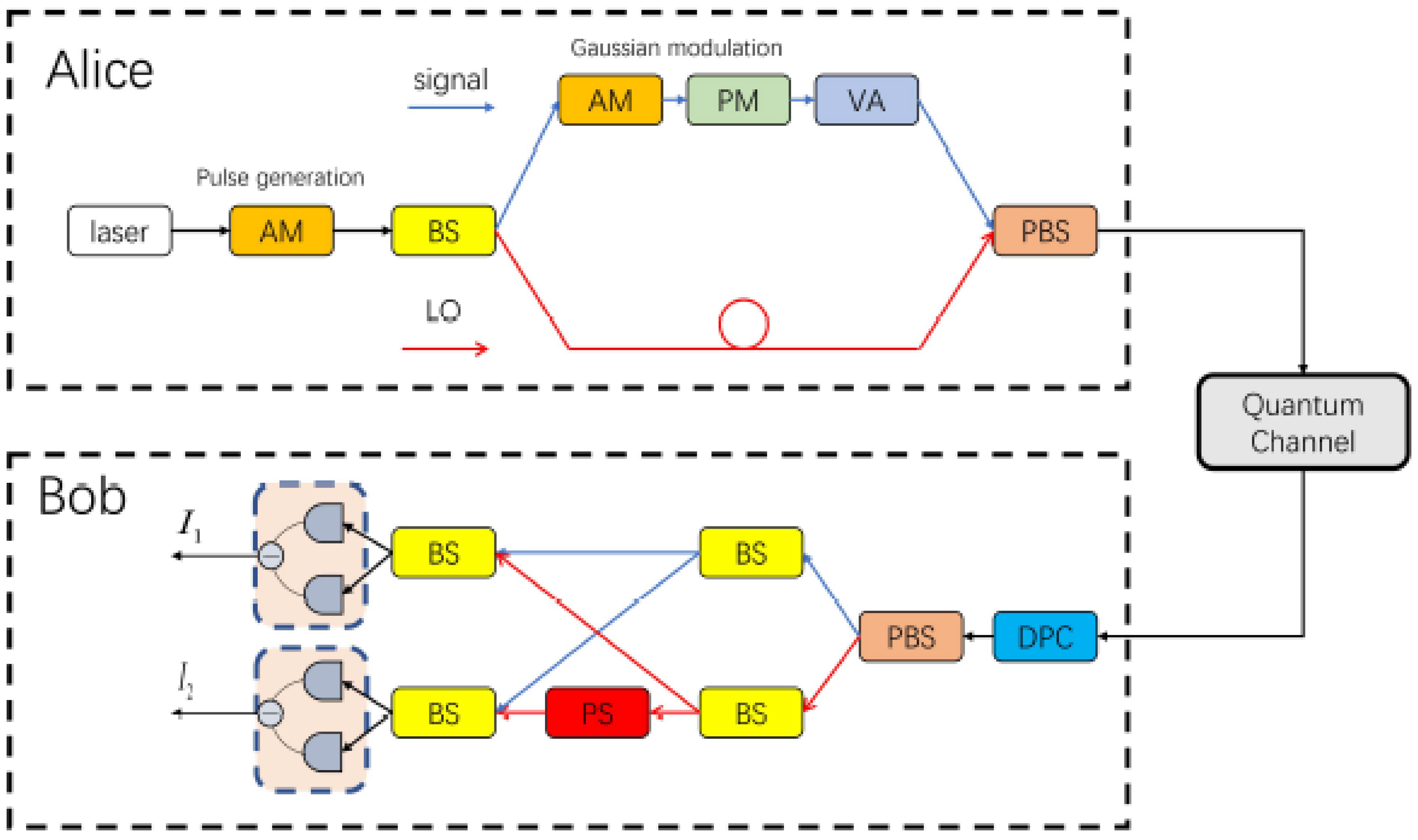

Fig. 1. Schematics layout of the heterodyne detection GMCS protocol. AM: amplitude modulator; PM: phase modulator; BS: beam splitter; PBS: polarization beam splitter; VA: variable attenuator; DPC: dynamic polarization controller; PS: phase shifter.

- Alice generates quantum signals with Gaussian modulation.
- At the receiver side, The heterodyne detection scheme comprises the imperfect optical phase shifter and two balanced homodyne detectors.
- The actual shifting phase is π/2-θ due to the non-ideal external factors.

Entanglement-Based description of measurement angular error

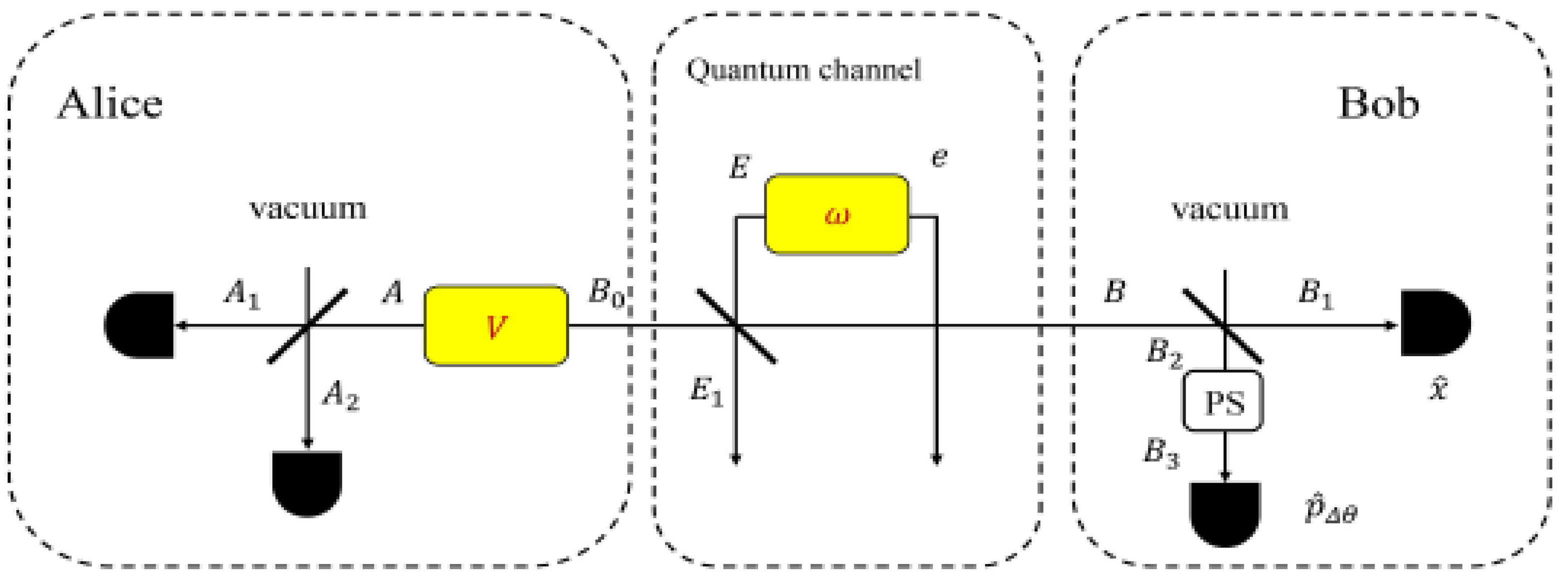

Fig. 2. The EB description of measurement angular error in CV-QKD scheme using heterodyne detection.

- Different from the ordinary heterodyne detection, a phase shift operation is performed while measuring P quadrature, as shown in Fig. 2.
- The heterodyne detection results can be expressed as

$$x_{B_1} = \frac{1}{\sqrt{2}} x_B + \frac{1}{\sqrt{2}} x_v,$$
$$p_{B_3} = -\sin\theta \cdot x_{B_2} + \cos\theta \cdot p_{B_2}.$$

Calibration and compensation method

- From the above equations, we can acquire the concrete formulation about covariance and variance, which can be measured directly from the practical experiment.

$$\langle p_{B_3}, x_{B_1} \rangle = -\sin\theta \cdot \left(-\frac{V_B}{2} + \frac{1}{2}\right),$$
$$V_{B_1} = \frac{1}{2}(V_B + 1).$$

- Then, the mean value of the error angle can be simplified as

$$\theta = \arcsin\left(\frac{\langle p_{B_3}, x_{B_1} \rangle}{V_{B_1} - 1}\right)$$

- Finally, the compensation method is realized in data post-processing, Considering the finite number of bits in ADC, the accuracy of compensation accuracy is limited, so it is not a real-time adjustment and will have an impact on efficiency.

Simulation and results

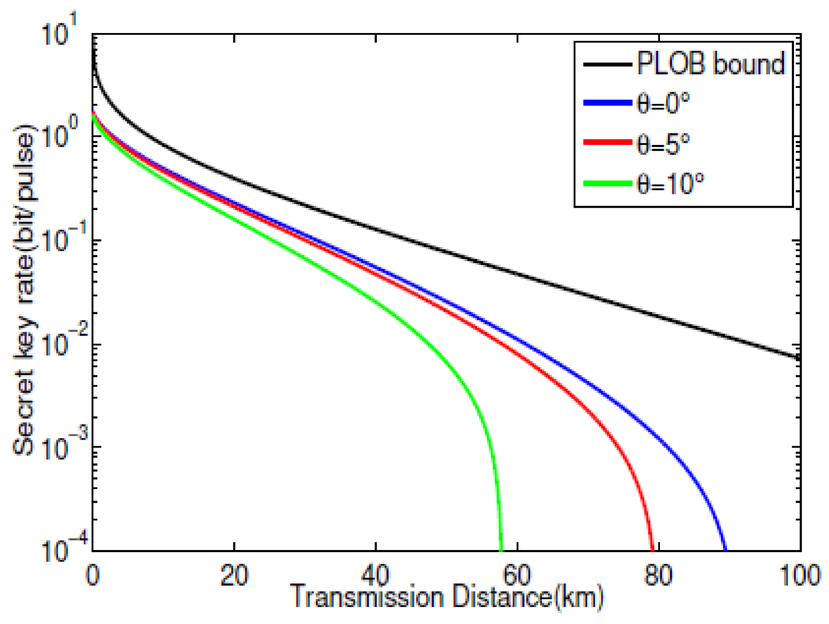

Fig. 3. The secret key rate versus the transmission distance with different measurement angular error.

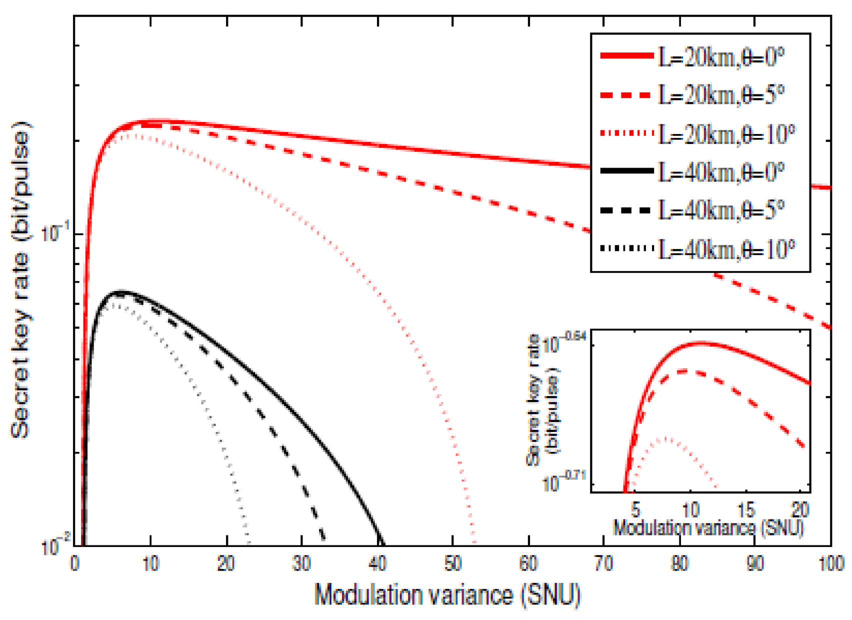

Fig. 4.The optimal modulation variance for the systems with different measurement angular error.

- The secret key rate as a function of transmittance distance with different measurement angular errors is calculated, as depicted in Fig. 3. Three colors of lines, green, red and blue correspond to different angles, and the black line represents the PLOB bound [4].
- The existence of measurement angular error can also cause the changes of optimal modulation variance [5], as depicted in Fig. 4. The curves of the secret key rate versus optimal modulation variance with measurement angular is simulated.

Conclusion

- we propose a method to estimate the measurement angular error from heterodyne detection, which can then be compensated through data processing. And simulation results suggest that the performance of the practical systems can be significantly improved when properly dealing with the measurement angular error.
- Undoubtedly, it is worth observing that our work is to strengthen practical security resulted from devices' imperfection.

Reference

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