Noise characterization for co-propagation of classical and CV-QKD signals over fiber and free-space link

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Abstract:
Real-time CV-QKD receiver achieves peak 2.9 Mbit/s secret-key-rates over 12.8 km of fiber, while co-propagating 15 classical channels, separated 1 nm from the quantum signal. Performance degrades at higher launch powers due to crosstalk.

1. Introduction

Continuous-variable quantum key distribution (CV-QKD) provides information-theoretic security when distributing secret random keys. Exploiting the quantum properties of weak coherent states, CV-QKD protocols utilize mature telecom technologies and use either Gaussian or discrete modulation. In this work, we assume a realistic trusted noise scenario [1]. There is growing interest in the coexistence of CV-QKD with classical signals, especially the impact that practical implementations may have on optical networks. Recently, joint propagation of wideband fiber transmission of 100 coherent dual-polarization (DP) 16-ary quadrature amplitude modulation (QAM) wavelength-division multiplexing (WDM) channels, and CV-QKD signals with an average secret key rate of 27.2 kbit/s was implemented in [2]. The inter-core crosstalk impact of CV-QKD with classical channels in multi-core fiber has been shown in [3]. The tolerance of CV-QKD to co-propagation with C-band DWDM channels is investigated in [4], with the quantum channel in the S- and L-bands. This paper shows the impact of wavelength division multiplexing of CV-QKD and classical channels in the C-band, with different classical channel total launch powers over optical fiber and a free-space optical (FSO) link.

2. Experimental Set-up

Figure 1 shows an offline transmitter (Alice) with a <100 kHz linewidth external cavity laser (ECL), IQ optical modulation for probabilistically shaped 256-QAM signals and a 250 Mbaud symbol rate with 50% pilot symbols. Alice's average modulation variance was 8 shot-noise units (SNUs). A real-time receiver (Bob) operates in calibration and quantum signal reception mode. Key system capabilities include a local ECL as a local oscillator (LO) into an optical hybrid, digitization of analog-to-digital converter (ADC) output at 2 GS/s, and real-time digital signal processing (DSP) for calibration and quantum signal recovery. DSP includes frequency-offset compensation, filtering, equalization, pilot-based phase recovery [5], and parameter estimation. Bob follows the trusted noise assumption and all the CV-QKD receiver losses due to coupling and the optical bandpass filter (BPF), with roughly 1.00 nm in 3dB bandwidth, are considered for the quantum efficiency, resulting in a decrease in efficiency from 67% to 35%. In Bob, an optical isolator between the optical switch and the hybrid prevents back reflections from the local LO. Real-time post-processing on a graphics processing unit (GPU) evaluates security via excess noise. In addition, the CV-QKD signal is combined with 15 classical 45 GBd DP-64-QAM WDM channels, placed on a 50 GHz grid. The classical transmitter consists of 15 ECLs of which the outputs are multiplexed into odd and even channels and are modulated by two dual-polarization IQ-modulators (DP-IQMs) driven by a 4-channel 100 GSa/s digital-to-analog converter (DAC). The output is amplified using an erbium-doped fiber amplifier (EDFA) and

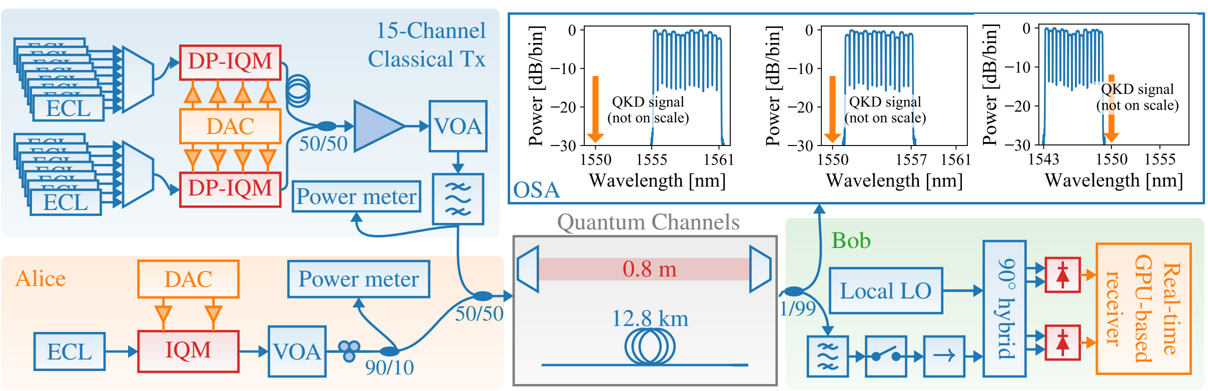

Fig. 1: Experimental set-up of co-propagation of CV-QKD and 15 classical channels over fiber and FSO

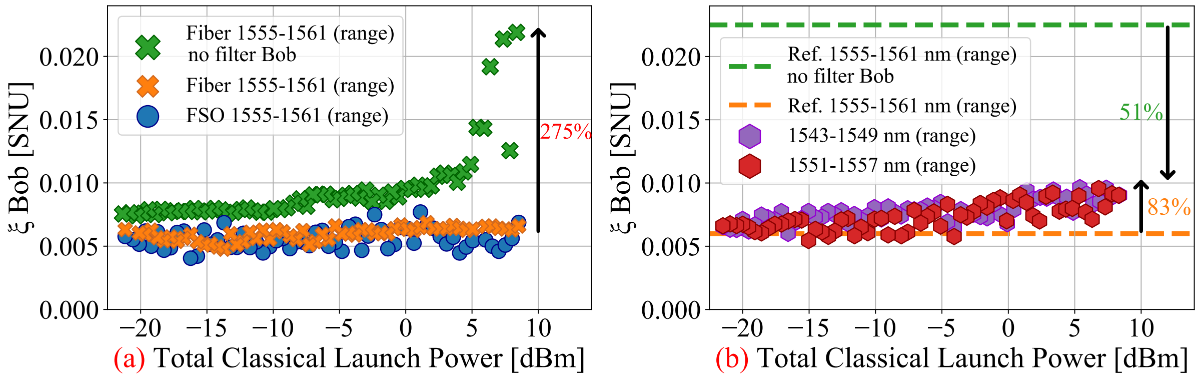

Fig. 2: (a) Bob's excess noise evaluation for different total classical launch powers in fiber and FSO of the 15 channels between 1555-1561 (b) Same analysis with the 15 channels between 1551-1557 and 1543-1549 range

band-pass filtered by an optical processor to minimize amplifier noise in the CV-QKD band. After combining with the CV-QKD signal, the light is collimated and directed through mirrors before being collected back into a fiber. The free space propagation distance is 0.8 meters with a corresponding loss of 3.85 dB. For the second experiment, a total of 12.8 km of fiber was employed. The spectrum of the classical channels is obtained by an optical spectrum analyzer (OSA), where three configurations were studied. The first case is 15 classical channels between 1555 and 1561 nm, the second between 1551-1557 nm, and lastly 1543-1549 nm. The classical receiver follows the same setup as in [6].

3. Results

Figure 2a shows the evolution of measured excess noise in Bob for different total classical launch powers. The classical channels were between 1555-1561 nm, with a total launch power from -21.37 to 8.46 dBm. The blue dots represent the results of the free-space experiment, where no Raman scattering occurs. This experiment is equivalent to a back-to-back set-up with additional loss. The green crosses constitute the fiber experiment results, with the same classical channel location, with no optical BPF added on Bob's side. The orange crosses correspond to the results in fiber with BPF. Each dot and cross corresponds to the average excess noise of a 30-second capture with multiple data blocks with 1×10^7 symbol length. Without the BPF in Bob, the excess noise increases with larger total launch power, mainly due to amplified spontaneous emission (ASE) from the amplifier in the classical transmitter. At maximum total launch power, there is an increase of 275% in excess noise compared to the other two experiments in the same range. With the BPF, no impact on excess noise between the measurements in fiber and FSO was observed, due to enough separation of the CV-QKD and classical channels, apart from random fluctuations.

In Figure 2b the classical channels were positioned 1 nm apart from the CV-QKD signal, on each side, separately. For maximum power, both measurements with the BPF, show an 83% increase of excess noise compared to the orange cross reference. This increase can be justified by the proximity of the classical channels and due to the roll-off of the BPF. The excess noise is 51% smaller than the highest green cross reference from Figure 2a. Considering the same experimental parameters and assumptions in [6], the secret key rate (SKR) with 12.8 km of fiber would decrease from 4 Mbit/s, at the lowest total launch power, to 2.9 Mbit/s at the highest.

4. Conclusion

This work shows how ASE primarily affects the excess noise under different classical channel and quantum receiver conditions. This allows for a comprehensive study to optimize classical channel placement and filter parameters to mitigate extra noise influence due to crosstalk and maximize the secret key rate. We note that the range of the total launch powers might not be sufficient to study stimulated Raman scattering effects, which will be further explored in future work.

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