Quantum Communication in Broad Daylight: A Field Demonstration of Quantum Keyless Private Communication

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Introduction

Background: Quantum Key Distribution (QKD) enables quantum-secured communication but remains complex and costly to implement and impractical in daylight links. QKPC provides a simpler, noise-resilient alternative without key exchange.

Objective: Experimentally demonstrate a polarization-multiplexed Quantum Keyless Private Communication (QKPC) system operating in a daylight free-space link, validating its robustness to high background noise and its potential for space-based implementations. [1, 2].

QKPC Overview

- Information encoded directly on the quantum states (weak coherent pulses).
- No keys required.
- Eve only receives a part of the signal (γ), based on the Wiretap model [3].

Steps: Encoding; State preparation; Measurement; Decoding.

On-Off Keying (OOK) encoding:

- Information encoded on the number of photons:

$$|\psi_0\rangle = |0\rangle,$$
$$|\psi_1\rangle = |\alpha\rangle.$$

Polarization encoding:

- Information encoded also on the polarization:

$$|\psi_0\rangle = |\alpha\rangle_H |0\rangle_V$$
$$|\psi_1\rangle = |\cos\theta\beta\rangle_H |\sin\theta\beta\rangle_V$$

Eve: Can discriminate the states optimally (Helstrom Bound). Modeled by a symmetric binary channel with mutual information, I_E.

Bob: Uses practical detection schemes. Modeled by an asymmetric binary channel with mutual information, I_B.

Quantum Bit Error Rate (QBER): Given by the error probability in discriminating the states

Private Capacity (C_p): $C_p(\gamma) = \max_{q_0} [I_B - I_E]$

Δ: Average number of background photons

Experimental Setup

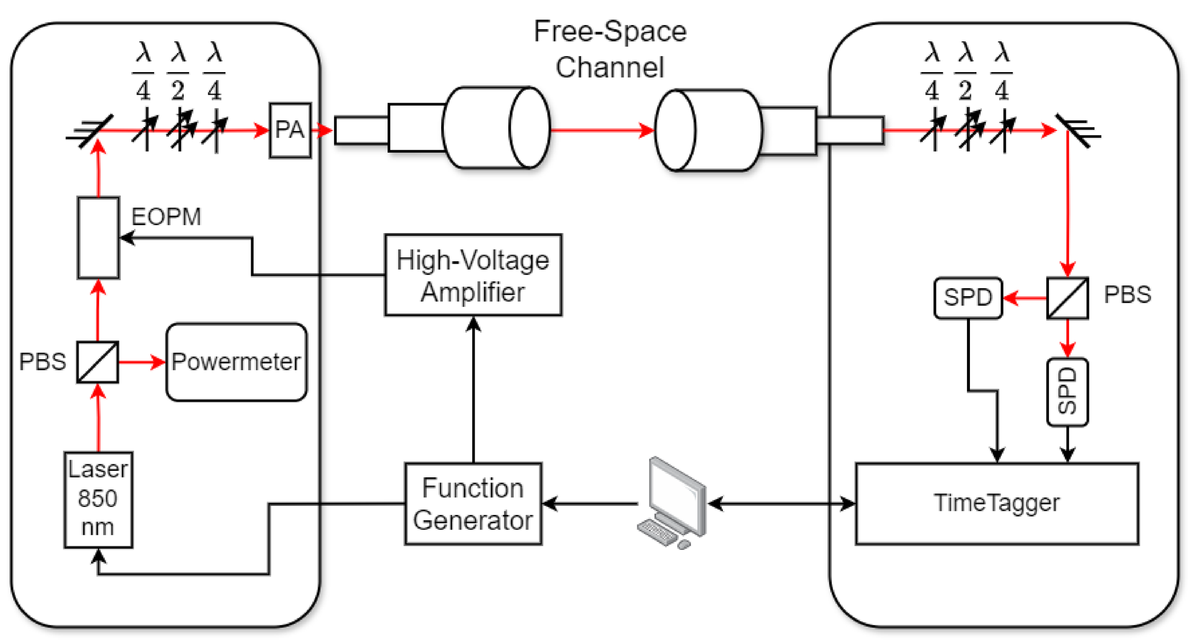

Figure 1: A portable setup capable of implementing both implementations of the QKPC protocol. PBS: polarizing beam splitter. EOPM: electro-optic polarization modulator. PA: passive attenuator. SPD: single photon detector. λ4 : quarter-waveplate. λ2 : half-waveplate. The black arrows are electrical connections.

Free-space daylight quantum communication

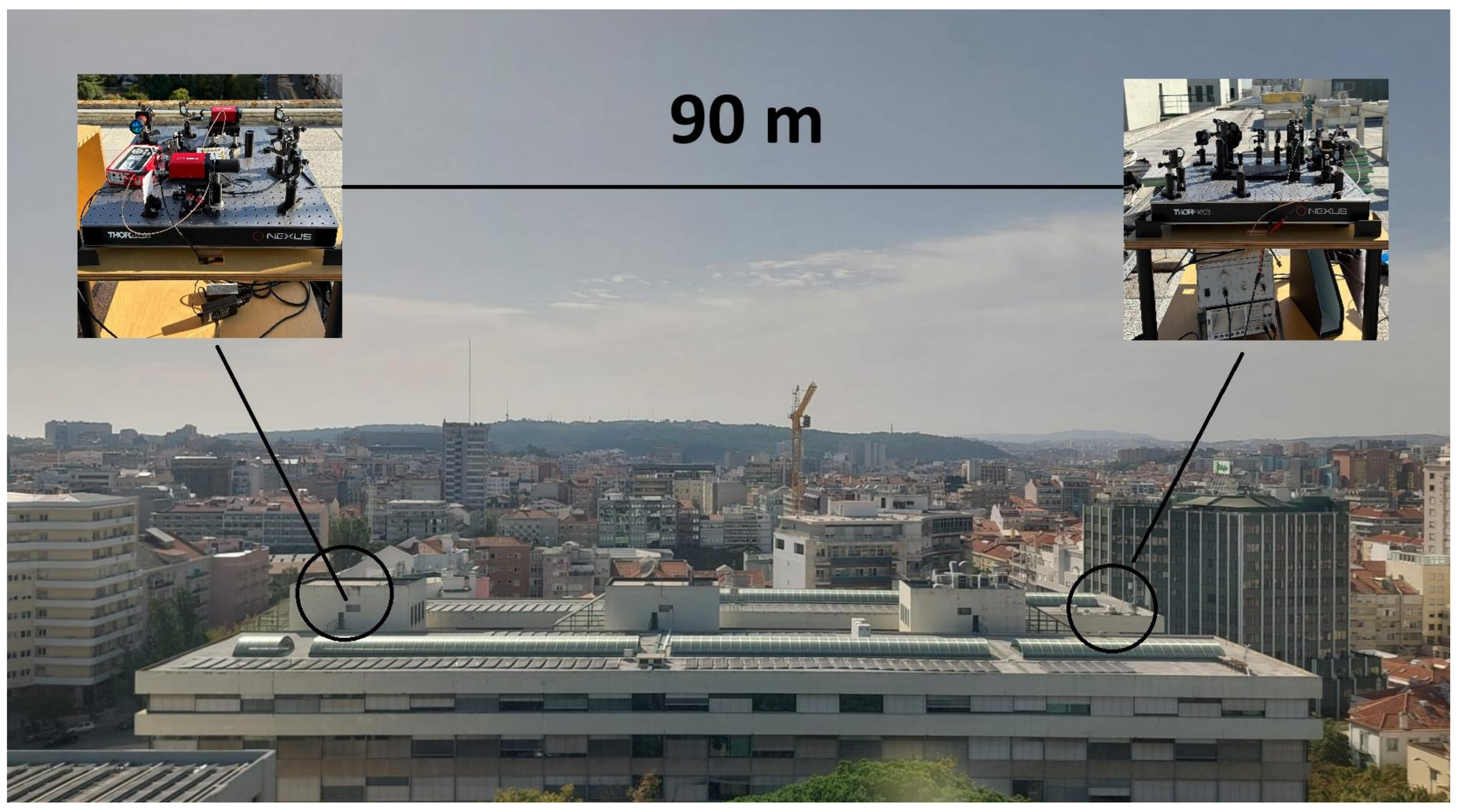

Figure 2: Daylight free-space quantum communication link used for the QKPC field experiment. The transmitter and receiver were placed on opposite sides of a rooftop, separated by a 90 m line-of-sight path. The link operated under clear-sky daylight conditions to evaluate the system's resilience to background noise.

Resilience to Daylight Noise

Conditions	Relative Brightness	Typical Brightness (W m^{-2} Sr μm^{-1})	Photons per Pulse (Δ)
Cloudy Daytime	1.0	150	7.4
Hazy Daytime	10^{-1}	15	7.4×10^{-1}
Clear Daytime	10^{-2}	1.5	7.4×10^{-2}
Full Moon Clear Night	10^{-5}	1.5×10^{-3}	7.4×10^{-5}
New Moon Clear Night	10^{-6}	1.5×10^{-4}	7.4×10^{-6}
Moonless Clear Night	10^{-7}	1.5×10^{-5}	7.4×10^{-7}

Figure 3: Comparison of the number of noise photons received per pulse under different weather conditions.. Taken from [2].

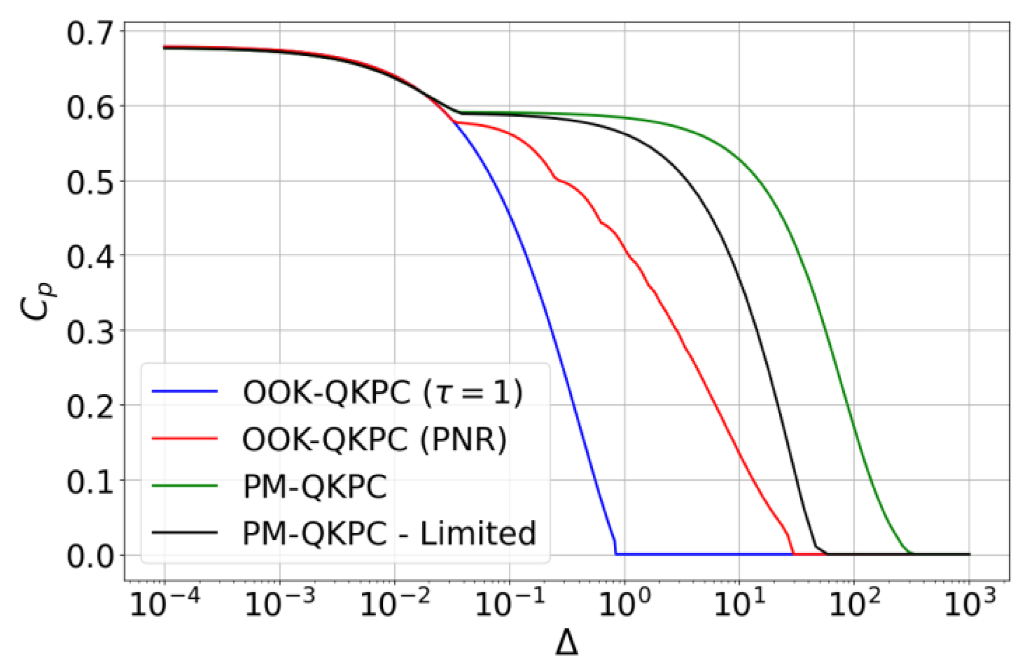

Figure 4: Plot of the maximum private capacity as a function of the photon noise, Δ, for γ = 0.1 for different measurements strategies. Taken from [2].

Experimental Results

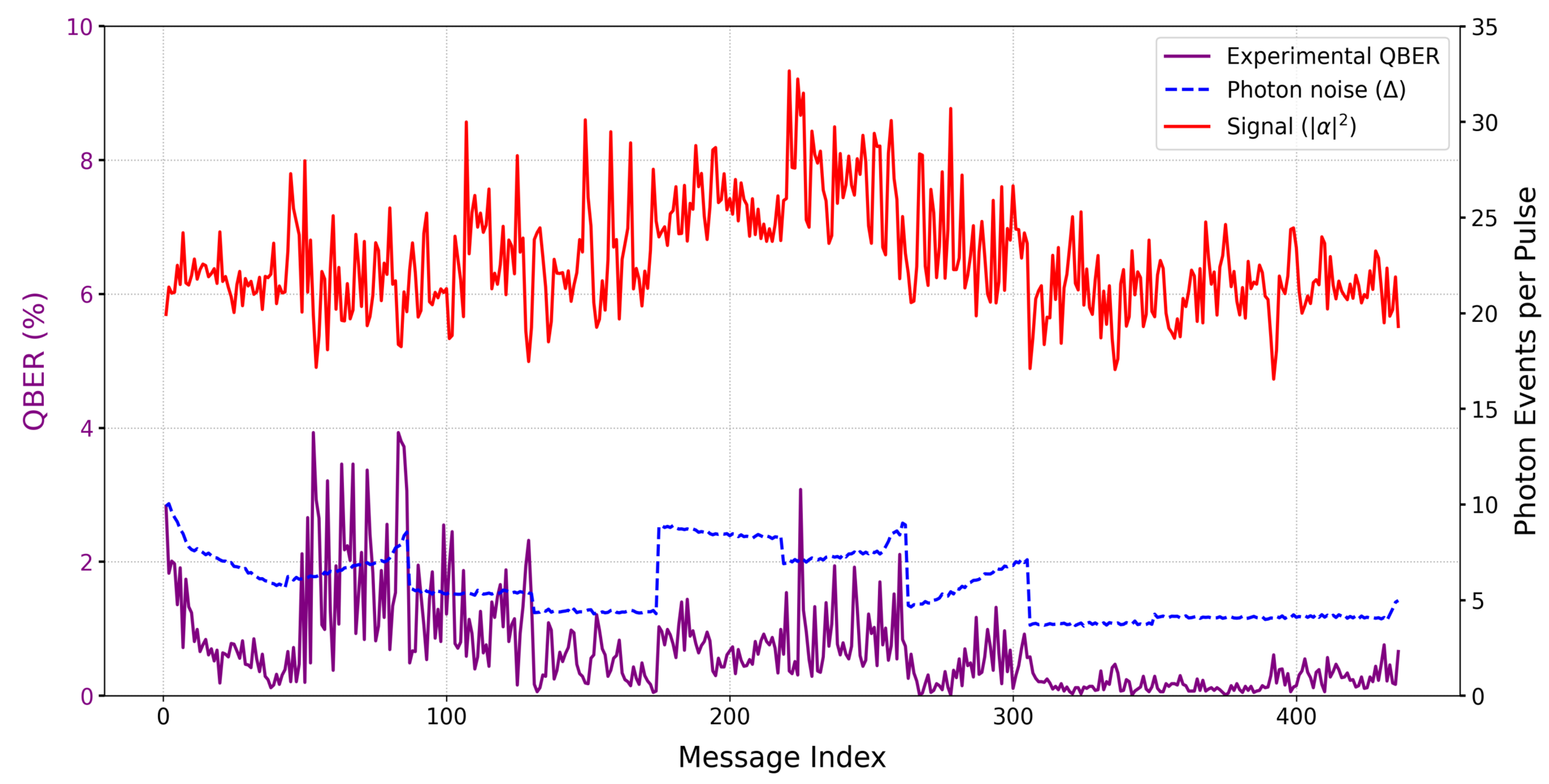

Figure 5: Experimental QBER, photon noise, and signal levels measured during the daylight free-space QKPC field trial. Data were collected in the afternoon (around 15:00) under clear-sky conditions over a continuous period of approximately 2 hours. Each acquisition consisted of a 10-second measurement followed by a 10-minute waiting interval before the next acquisition.

Conclusions

- Demonstrated a 90 m daylight free-space implementation of Quantum Keyless Private Communication (QKPC).
- QBER remained below the secure threshold, validating QKPC's robustness in real-world daylight conditions.
- The experiment demonstrates that QKPC enables stable, low-complexity quantum communication even under strong daylight noise.

References

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[2] - Mendes, P. N., Rusca, D., Zbinden, H., & Cruzeiro, E. Z. Quantum Keyless Private Communication under intense background noise. arXiv preprint arXiv:2505.07940, 2025

[3] - Aaron D Wyner. The wire-tap channel. Bell system technical journal, 54(8):1355–1387, 1975.

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