

Free Space Quantum Key Distribution with Coherent Polarization States

Dominique Elser (1), Tim Bartley (1,2), Bettina Heim (1), Christoffer Wittmann (1), Denis Sych (1)
and Gerd Leuchs (1)

1: Institute of Optics, Information and Photonics, Max Planck Research Group, University of Erlangen-Nuremberg,
Günther-Scharowsky-Str. 1, Building 24, 91058 Erlangen, Germany
delsel@optik.uni-erlangen.de

2: Physics Department, Blackett Laboratory, Imperial College, London SW7 2BZ, United Kingdom

Abstract

We present an experimental demonstration of Free Space Quantum Key Distribution using Continuous Variables. A local oscillator, inherent in the setup, also acts as spatial and spectral filter thus allowing unrestrained daylight operation. Our prepare-and-measure setup uses binary encoding on coherent polarization states. The quantum states are transmitted over a 100m free space channel on the roof of our institute's building. We employ simultaneous homodyne detection on two conjugate Stokes parameters. Signal and local oscillator are combined in a single spatial mode which auto-compensates atmospheric fluctuations and results in an excellent interference.

Introduction

In classical telecommunication, free space optics (FSO) can help bridging the "last mile" between network nodes and users where installing a glass fiber is often time-consuming and cost-intensive. Furthermore, FSO is utilized for satellite communication. In the domain of quantum key distribution (QKD) [1] FSO offers an additional benefit: Since fiber losses limit the maximum link range, FSO using ground-to-satellite links is the only feasible way to accomplish QKD over large distances.

After the first demonstration of free space QKD in 1996 [2] several prepare-and-measure [2-6] and entanglement-based [7-10] systems have been implemented. Currently, the world record in distance is 144 km [6,9] and satellite QKD is in the starting phase [11,12]. A common feature of all systems up to now is the use of single-photon detectors which, however, are blinded already at low background light intensities. Spatial, spectral and/or temporal filtering has to be employed to reduce background light and daylight operation is still challenging.

In our system, we use an alternative approach: With the help of a bright local oscillator (LO) we perform homodyne measurements on weak coherent states.

Interestingly, apart from enabling the homodyne measurement, the LO fulfills additional functions in FSO:

- Spatial filtering: Only photons which are spatially mode-matched to the LO are detected. Any other stray light is effectively filtered out.
- Spectral filtering: Only photons within a frequency range given by the LO and the detector's electronics are detected.
- Spatial tracking: Atmospheric beam wander and distortions can easily be monitored in order to compensate for them.
- Timing generation: Atmospherically induced time jitter can be determined by applying a temporal modulation to the LO.

For a homodyne detection, a good interference of signal and LO is crucial. Stabilizing this interference would be a problem if, as usual, signal and LO were propagating as two separate beams. In our setup, however, we use polarization states which allow for co-propagation of signal and LO in one single beam. Thus the interference is intrinsically excellent and furthermore phase fluctuations in the channel are auto-compensated.

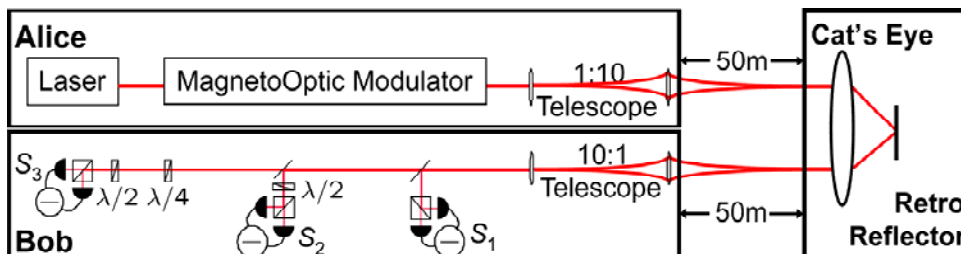


Figure 1: Experimental setup: Alice's laser emits a linearly polarized CW beam which later serves as a local oscillator for Bob's measurements. In terms of Stokes parameters, the local oscillator is S_1 polarized. Alice's magneto-optical modulator generates a weak signal in the S_2 component. The beam is expanded and sent to a retro-reflector at a distance of 50 m. Bob characterizes the reflected beam by homodyne measurements of the S_2 and S_3 components. The intensity of the local oscillator can be monitored by an S_1 measurement.

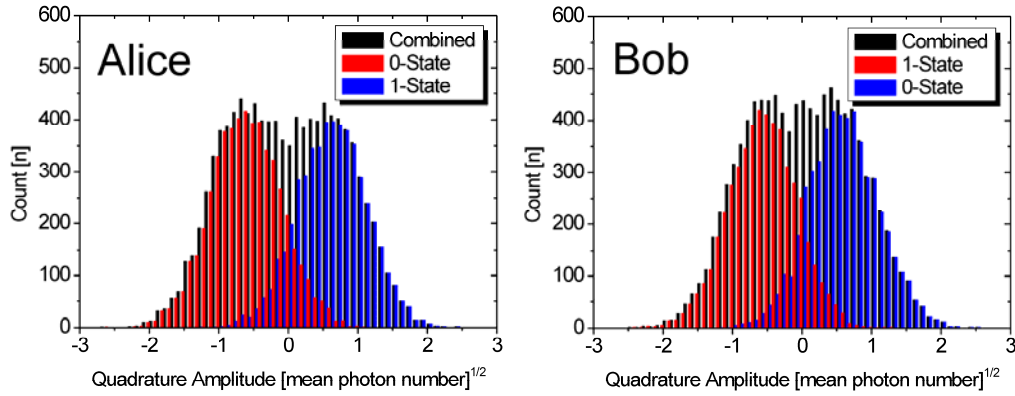


Figure 2: Exemplary measurements of marginal distributions along the signal quadrature S_2 . Alice: quantum states measured directly after generation, Bob: quantum states transmitted through a 100 m atmospheric channel. 0- and 1- state correspond to the signal states $|+\alpha\rangle$ and $|-\alpha\rangle$, respectively. Attenuation effects have been factored out.

Experimental setup

The setup in Fig. 1 follows the principles of our earlier work, see [13]. We use a grating-stabilized diode laser whose wavelength of 809 nm lies within one of the atmospheric transmission windows [1]. The linearly polarized laser beam (S_1 in terms of Stokes parameters) will later serve as local oscillator in Bob's measurement. A magneto-optical modulator employs the Faraday effect to tilt the linear polarization by small amounts. This modulation can be seen as generating a weak S_2 component in the same spatial mode as the local oscillator. After expansion by a telescope, the signal/LO beam is sent over the flat roof of our institute's building and retro-reflected after 50 m. Bob performs a simultaneous homodyne measurement of the conjugate S_2 and S_3 quadratures, enabling him to reconstruct the Q function.

Results

Up to now we have characterized the signal quadrature (S_2) after atmospheric transmission. Exemplary results are presented as the S_2 marginal distributions in Fig. 2. We compare the distributions before (graph "Alice") and after (graph "Bob") transmission through the atmospheric channel. The light intensity at Alice's station is adjusted such that Bob's measured intensity is the same as Alice's. Thus attenuation is effectively factored out and the broadening of Bob's distribution can be directly determined. This broadening is a measure for the atmospherically induced excess noise which, if too high, would compromise security. However, we find no significant broadening of Bob's states suggesting that atmospheric excess noise would not prevent our scheme from establishing a QKD link.

Conclusions and Outlook

We have presented the first CV quantum communication through a real-world atmospheric channel. Our results indicate that a QKD link can be established in urban environments at daylight.

The next step is a more extensive characterization of the 100 m retro-reflector link including measurements of the Q function. Afterwards we plan to set up a real point-to-point link of approx. 1 km. Furthermore, we want to increase the pulse rate of our setup (1 MHz at the moment) and investigate more complex signal alphabets.

References

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