Quantum key distribution over WDMs and optical switches to combine the quantum channel with synchronization channels

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Abstract We use standard CWDM-telecom equipment and optical switches to combine entangled photons with all needed signalling channels and perform QKD via a single optical fiber over a distance of 25km.

Introduction

Quantum cryptography (QKD) with entangled photons [1] has been demonstrated both in the laboratory and in the real world [2]. However to prove to be a real contender for commercial QKD systems, important additions to those early prototypes needed to be made.

In this work we demonstrate the two main improvements allowing the introduction of entanglement based QKD in existing fiber networks:

We show the capability of standard CWDM equipment to combine different synchronization channels in one fiber. Additionally, we actively monitor and correct the dynamic polarization rotation in fibers to form a polarization stable channel for the entangled photons.

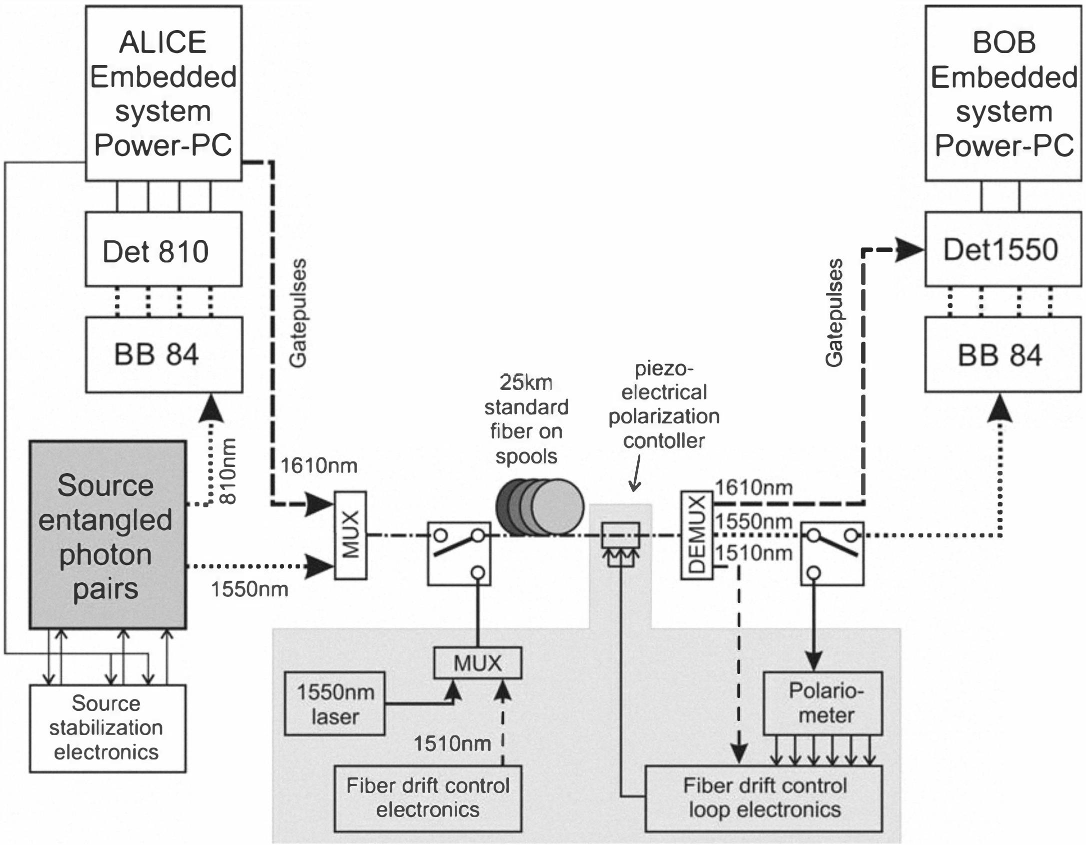

Figure 1: The source of entangled photon pairs (dark grey box) delivers polarization entangled photons, which are used to build up a secret key. The BB84-module analyses the 810nm-pair photon locally and the photons are detected (Det 810). For all those events a pulse is generated at 1610nm that is wavelength multiplexed (MUX) to the single photon. After the transmission through fibers in spools, the signals are separated by a DEMUX. This gate-pulse is used to open a short time window (2.5ns) on the InGaAs-APDs (Det1550). Within this short time the entangled partner photon is expected, also analyzed by a BB84-module. The embedded systems on both sides get the corresponding detector signals and the onboard QKD-stack generates the secret keys.

Setup

The core of our setup is a source of polarization entangled photon pairs. There we generate pairs of photons at different wavelength, the 810nm-photon is detected locally near the source at Alice by silicon based APDs with high efficiency. The other photon at 1550nm is sent through optical fiber spools to Bob and is detected by an InGaAs-APD. Unfortunately this detector needs to be gated to have low dark counts, therefore a reference signal on a time-stable channel must indicate Bob that a potential photon will reach him shortly. Here we used wavelength multiplexed gating signals.

Difficulties in multiplexing a quantum channel

The signal transmitted on the quantum channel is at the order of 100dB less powerful as a typical classical channel. The influence from the classical channel must even be further decreased to reach the level of dark counts at the detectors, so a channel isolation of 140dB is desired. We see different sources of cross-talks in our setup:

1. Despite the main lasing wavelength of typical CWDM-laser diodes being multiples of 20nm away from the quantum channel, the additional generated weaker radiation reaches also 1550nm and is coupled inside the quantum channel by the MUX. These millions of potential background photons must be carefully separated before the MUX by additional add/drop-filters (not shown in Fig. 1).

2. The channel isolation of the DEMUX must be high so the classical channels are really separated and no dominant classical light enters the single-photon detectors. Therefore additional add/drop-filters (also not shown in Fig.1) must be placed in the quantum channel between the DEMUX and the detectors.

Both effects 1 and 2 are linear effects. We could apply all needed elements in the setup (without the fiber spools) and could eliminate all the additional background counts. We even applied the needed classical communication on two CWDM channels (1470nm and 1490nm) and achieved low additional counts on the quantum channel. The situation changed drastically, as we added long fiber spools:

3. Even small nonlinear fiber effects add up to large and potentially harmful contributions over longer fiber lengths, at least for measurements on a single photon level. The predominant form of noise in our case is Raman-scattering. It is strong enough to prevent the operation of a quantum channel multiplexed to classical communication over CWDM.

Our approach is to use a time-multiplexed synchronization whereby the classical pulse is sent a few tens of ns after the single photons. This guarantees that the quantum signal is not dwarfed by the background.

Very recently another way to overcome the Raman-effect was tested out with entangled photons: The use of DWDM and therefore classical wavelength even very close to the quantum channel. It seems to be the only way to avoid this dominant background noise source, present at our CWDM-system [3,4]. Unfortunately, present DWDM-filters show higher losses to achieve the needed channel isolation.

Active polarization control for entangled photons

For polarization encoded qubits it does not suffice to use only one polarization basis for tracking (as implemented by all commercially available products), because the phase of qubit superpositions is not fixed. Therefore two non orthogonal probe polarizations and a polarimeter analyzing all three Stokes vectors are needed.

A possible scheme would be to use the probe signal at a wavelength different to that of the single photons, which is combined with the quantum channel by a wavelength division multiplexing (WDM) module. However, this corresponds to the previous case of transmitting a classical signal besides the quantum channel. To prevent crosstalk, we tested a CWDM system and tried to track the polarization change of 1550nm with the probe signal in the adjacent channels of 1530nm and 1570nm. This scheme did not succeed, because the polarization controller does stabilize the probe polarization, but due to its slight wavelength dependent action the qubit polarization is not sufficiently controlled.

The only working solution we found is to have the probe at the same wavelength (1550nm) as the quantum signal. This requires a periodic switching of the quantum channel between qubit and probe signal transmission.

Analyzing the polarization state of the probe pulse gives information about the change in the fiber which in a second step is corrected using an electronic polarization controller.

Conclusions

We present a fully operational QKD setup based on entangled photons. Detector synchronisation signals and polarisation drift control pulses are multiplexed on the same fiber as the quantum channel. These modifications allow the implementation of entanglement QKD into existing fiber networks.

References

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