Dense-wavelength division multiplexing of quantum and classical communication over a deployed fiber link enabled by up-conversion assisted detectors

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Abstract

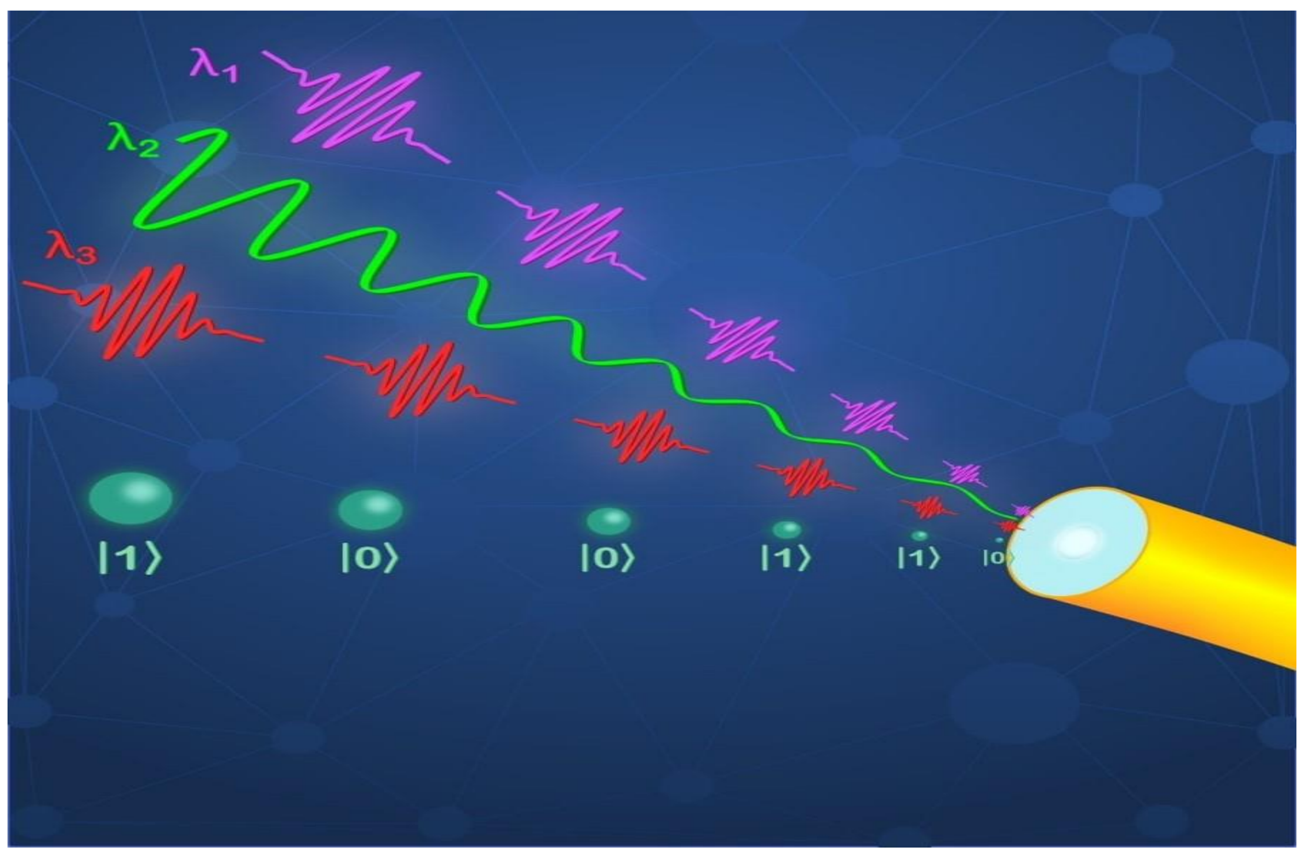
This work faces the open issue of using lit fibers for QKD applications, recording an important progress with respect to the previous results. By co-propagating a classical laser into a different C-band DWDM channel during a discrete-variable QKD experiment, we showed that a home-made detector exploiting the sum-frequency-generation to convert telecom wavelength photons into shorter wavelength ones, detectable by silicon-based photon counters, can manage a classical launch power of 4 dB higher than the one affordable by a commercial InGaAs detector.

Introduction

The coexistence of classical and quantum communications within the same fiber optics infrastructure is still an open challenge to be solved. In fact, most of the practical implementations of quantum key distribution (QKD) are accomplished by taking advantage of dark fiber channels, i.e. fiber-optics links totally dedicated to the transmission of quantum signals. This prevents the intense classical light to affect the qubit error rate, but strongly reduces the possibilities for a full deployment of QKD technologies in large-scale and realistic applications.

Looking for a solution several approaches have been tested, generally based on multiplexing of different degrees of freedom of photons [1,5] or employing QKD protocols that offer intrinsic endurance against the environmental noise[6,8], but the problem is far from being solved.

In our work we combined a dense-wavelength-division-multiplexing scheme with two different home-made single photon detection stages able to convert C-band photons into photons detectable by a silicon photon counter, by exploiting sum-frequency-generation process in nonlinear crystals.



Experimental setup

Our method exploits the properties of frequency-up-conversion-assisted detection of single-photon signals in the C-band, enabling the usage of silicon-based photon counters. The up-conversion process acts as an intrinsic and sharp filter in both polarization and wavelength, while the silicon-based single-photon detector boasts high-performing timing features, such as lower timing jitter and higher count rate with respect to the commercial single-photon detectors in the C-band, based on indium gallium arsenide (InGaAs) photon counters.

We built two similar setups, one converting the C-band single photons to 630 nm[9] and the other one to 860 nm.

SETUP:
-QKD transmitter module performing a three-state BB84 protocol with time-bin qubits produces single photons in the C-band;
-A periodically poled lithium niobate (PPLN) nonlinear crystal pumped with hundreds of milliwatts at 1064 nm (1950 nm) converts the C-band photons to 630 nm (860 nm) photons;
-The photons are filtered by cascade filters and sent to a silicon-based single-photon avalanche photodiode showing 40% (45%) of detection efficiency.

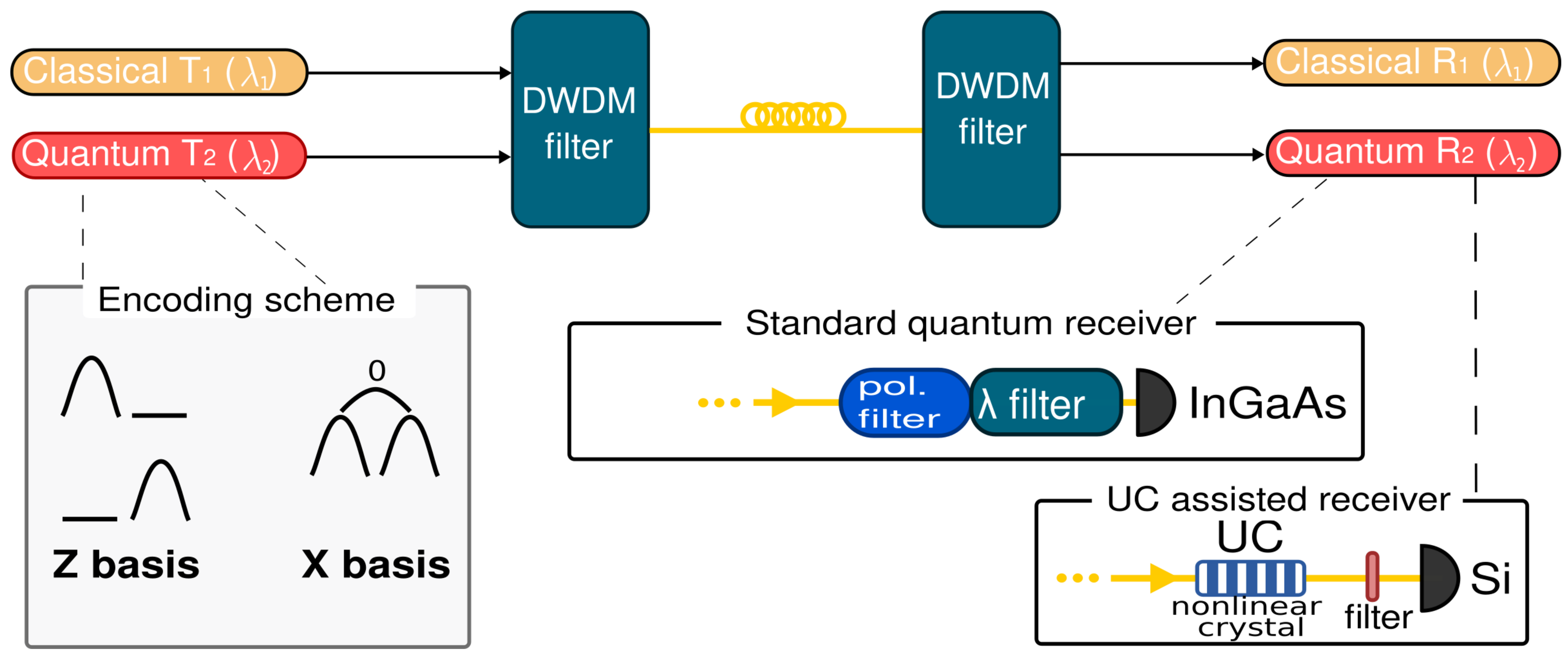


Figure 1: A classical transmitter (T1) is combined with a quantum transmitter (T2) in a dense-wavelength-division multiplexing scheme, by employing different wavelengths in the C-band which are co-propagated through the same fiber channel. The quantum receiver (R2) is rather composed by a standard detection module in the C-band, i.e., commercial InGaAs single-photon detectors equipped with optical filters, or by our up-conversion-assisted detection scheme equipped with silicon single-photon detectors.

Results

The overall detection efficiency of the whole 630 nm up-conversion detector (including conversion process, filtering, coupling and avalanche detector) is approximately 2%, while the total dark count rate, composed of intrinsic noise of the avalanche detector as well as of the remaining pump noise) is about 11 kHz.

Thanks to the choice of a long-wavelength pump laser, our second up-conversion device is less vulnerable to Raman scattering [10], exhibiting far lower noise than the first one, with an overall dark count rate of 900 Hz and an overall efficiency of around 12%.

Comparing the up-conversion detectors with a commercial InGaAs detector provided by a 100GHz filter to reproduce the up-conversion advantages, we experimentally demonstrated that our up-conversion module can afford 4 dB more classical light power than the commercial InGaAs detector[9].

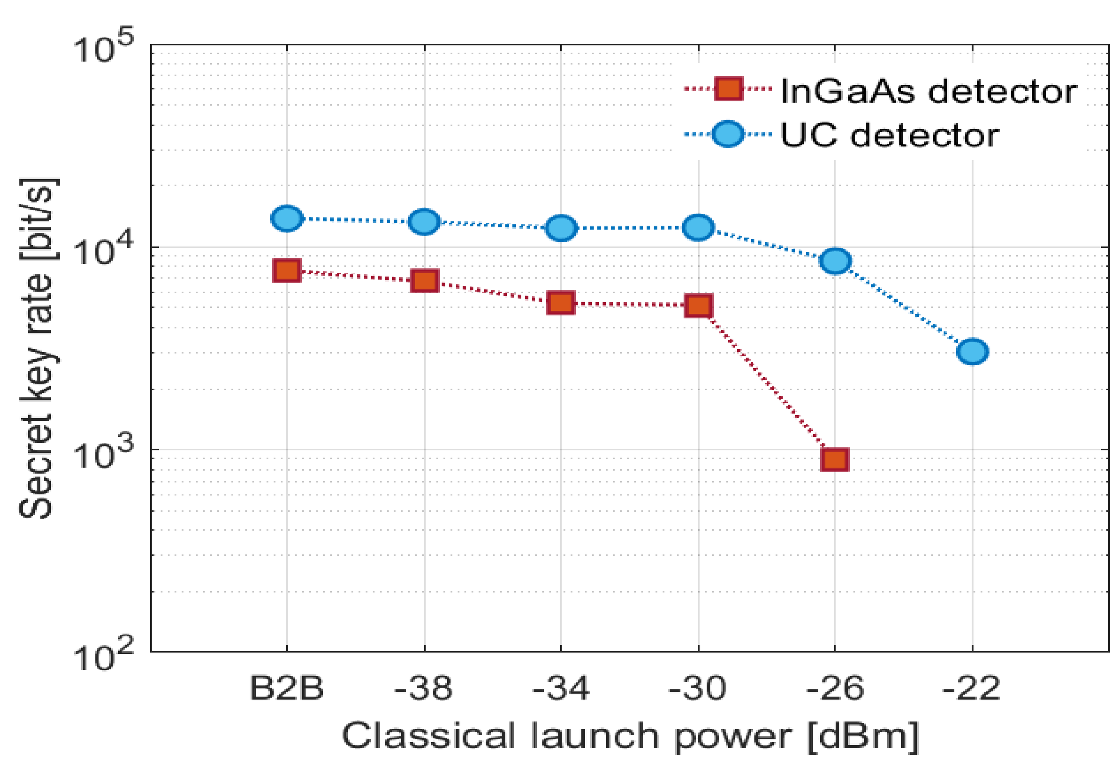


Figure 2: Secret key rate achievable with a three-state BB84 protocol in coexistence with a classical laser in a DWDM scheme, in a 3-dB channel loss. The achievable secret key rate is measured with the two different detection schemes reported in Figure 1, for increasing values of the launch power of the classical signal. The fist point (B2B) corresponds to the back-to-back configuration, where no classical laser is co-propagated. As a result, the up-conversion (UC) receiver performs better than the commercial InGaAs detector, by tolerating a classical launch power of about 4 dB higher.

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