European Conference on Optical Communication (ECOC) 2022 © Optica Publishing Group 2022

Distributing Polarization Entangled Photon Pairs with High Rate over Long Distance through Standard Telecommunication Fiber

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Abstract *Moderate photon pair rates limit fiber-based entanglement distribution. A bright non-degenerate photon pair source, designed for high idler photon detection efficiency on single-photon avalanche photodiodes and low signal photon dispersion in optical fiber, enables high pair rates even after propagating through 50 km standard telecommunication fiber.*

Introduction

Distributing entanglement over long distances is crucial for many quantum communication schemes, including several variants of quantum key distribution (QKD)[1]–[4]. Particularly, standard telecommunication fiber is an appealing method for entanglement distribution in metropolitan areas, since it is compatible with the existing telecommunication network. Limitations such as transmission losses and dispersion have forced some earlier demonstrations to work with a non-standard dispersion-shifted fiber[5],[6], compromising on its practicality. Due to the low photon pair rates, a number of demonstrations also relied on superconducting nanowire single-photon detectors which require a large overhead in resources in comparison with typical single-photon avalanche photodiodes (APDs)[7].

To address these drawbacks in fiber-based entanglement distribution, we present a highly non-degenerate entangled photon pair source based on type-0 spontaneous parametric down-conversion (SPDC) process[8]. The signal photon with a wavelength of 1310 nm falls in the zero-dispersion window of G.652D standard compliant fiber and has an intrinsic sub-nanometer bandwidth. The idler photon has a wavelength of 586 nm and is optimized for high efficiency for APDs. Starting with a local polarization entanglement visibility of more than 97%, we still observe a raw entanglement visibility of 92.5% with more than 10,000 s^{-1} of photon pair coincidence rate with a pair of APDs.

Experiment

Fig. 1 shows a sketch of the experimental setup. Time-correlated photon pairs are generated via SPDC in a periodically poled potassium titanyl

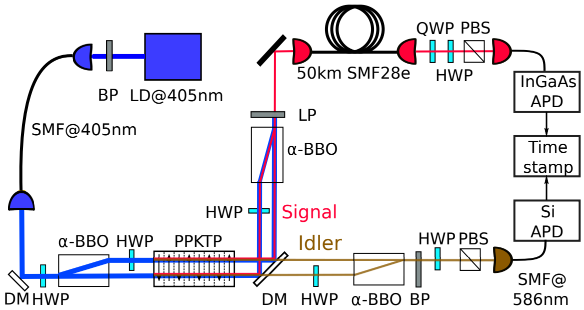

Fig. 1: Schematic of the non-degenerate entangled photon pair source.

phosphate crystal (PPKTP, $2 \times 1 \times 20\,\mathrm{mm}^3$) that is pumped with light from a grating-stabilized diode laser at a wavelength of 405 nm.

An α-BBO crystal splits the pump light into two paths of orthogonal polarizations (horizontal, H, and vertical, V) with a beam separation of 1 mm through birefringence. After transforming the H polarized pump light part back to V, the type-0 SPDC process in both conversion paths generates photon pairs in the $|VV\rangle$ state, which then are separated by wavelength using a second dichroic mirror. The polarization of the separated signal and idler photons from one of the pump paths is transformed to horizontal by two half wave plates (HWPs) designed for their respective wavelengths.

$|HH\rangle$ and $|VV\rangle$ photon pairs in the different pump paths of the same crystal are then spatially overlapped by two α-BBO crystal beam splitters to create polarization entanglement. By adjusting the relative power and phase between the two pump paths, polarization-entangled photon pairs are prepared into a $|\Phi^-\rangle$ state. An InGaAs-APD and a Si-APD detect signal and idler photons of the entangled pairs within a coincidence window.

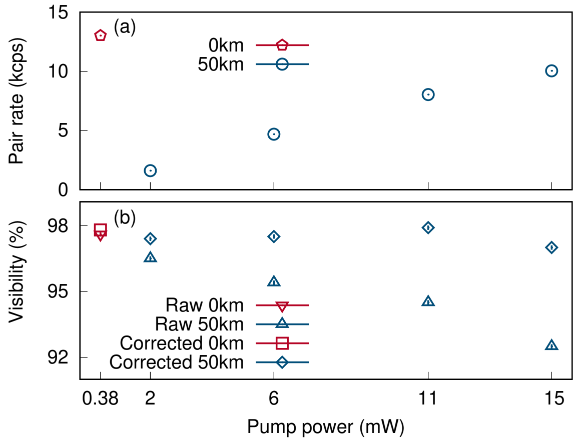

Fig. 2: (a) Average pair rates for different pump powers. (b) Visibility of polarization correlations as a measure of entanglement quality for different pump powers.

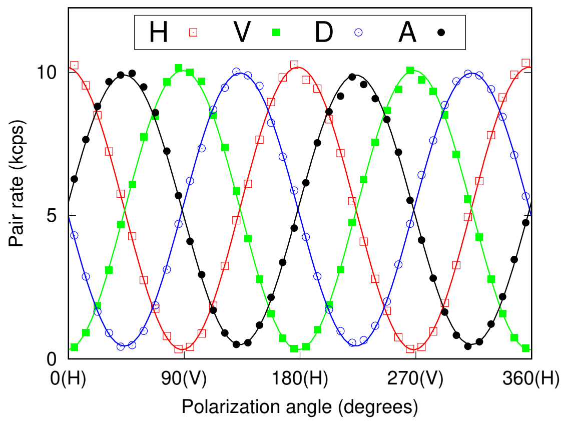

Fig. 3: Polarization correlations in both H/V and D/A bases measured at 15 mW pump power after transmission of the signal photons through 50 km SMF28e+ fiber.

Entanglement Distribution

To characterize the entanglement visibility, the combination of a motorized HWP and a PBS projects idler photons into one of the four linear settings (H, V, D, A) while the polarization on signal side is rotated over 360 degrees using the HWP.

We first examined entanglement quality locally at pump power of 380 μW, as shown in Fig. 1. Then the signal photons are coupled into a 50 km SMF28e+ fiber (-17 dB loss, G.652D standard compliant fiber) for entanglement distribution. The observed coincidence rates and visibilities for different pump powers are shown in Fig. 2. We observe that the coincidence rate increases mostly linearly with pump power.

The raw visibility at 15 mW pump power is 94.0$\pm$0.1% in the H/V basis, and 91.0$\pm$0.2% in the D/A basis, corresponding to an average visibility of 92.5$\pm$0.1% (see Fig. 3). After correction for background coincidences, the average visibility reaches 97.1$\pm$0.1%. The pair rate averaged over H/V and D/A bases is 10,033$\pm$16 s^{-1}.

Conclusion

In conclusion, we present a novel entangled photon-pair source for long-distance fiber-based quantum communication purpose. With the measured pair rate and entanglement quality, the estimated quantum key rate in a BBM-92 like protocol[3] with our source would be 5,172 s^{-1}. Moreover, QKD applications using photons in the O-band have the advantage in that the quantum signal can co-propagate with light of classical internet traffic in C-band over the same fiber link[9]. We therefore believe that such a source can significantly improve entanglement distribution over metropolitan distances, permitting an integration of high-rate entanglement-based quantum key distribution into existing telecommunication network with realistic detection devices.

Acknowledgements

This work has been financially supported by the Quantum Engineering Programme through QEP-P1: Superconducting Nanowire and NRF2021-QEP2-04-P01: National Quantum-Safe Network, as well as the Ministry of Education and the National Research Foundation, Prime Minister's Office, Singapore.

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