Experimental demonstration of local area entanglement distribution between two distant nodes, coexisting with classical synchronization

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Abstract: We successfully demonstrate polarization entanglement distribution and classical time synchronization using a high-accuracy precision time protocol between two quantum nodes located ~250 meters apart using a single fiber simultaneously carrying both quantum and classical data.

1. Introduction

Entanglement distribution will be a key service in future quantum networks. During entanglement distribution, quantum information is carried by photons traveling over optical fibers from a central source to client nodes separated by long distances. The quality of the entanglement distributed to the nodes is limited by loss, noise, polarization mode dispersion, and cumulative transmission time fluctuations – all of which must be mitigated to offset their detrimental effects. Co-existence of the node synchronization protocol with the quantum signal on a single link can improve transmission delay measurements and reduce deployment costs. Here, we demonstrate polarization entanglement distribution between separated quantum network nodes (Alice and Bob) that are synchronized to a picosecond level in an architecture where the quantum signals coexist with a classical White Rabbit[1] high-accuracy precision time protocol (HA-PTP) signal [1].

2. Experiment

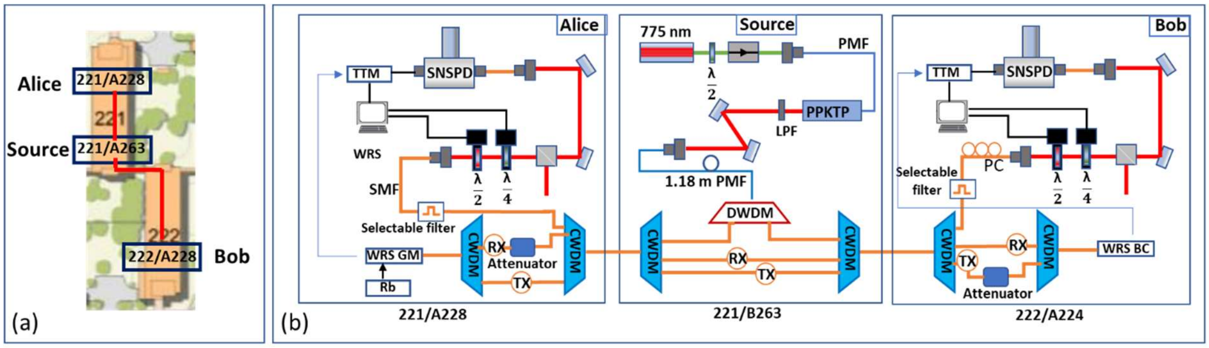

Figure 1. Experimental setup. (a) Schematic of the optical path between two NIST buildings. The distance between the nodes is around 250 m. The polarization entangled photon source is located between Alice and Bob. (b) The source (middle pane) emits a polarization entangled state and photons are sent to two receivers located at Alice and Bob (left and right pane, respectively). The receiver stations at Alice and Bob are both synchronized using the HA-PTP White Rabbit architecture. The HA-PTP and the quantum signal coexist in the same fiber, providing synchronization of the nodes to the picosecond level. SNSPD: superconducting nanowire single photon detector; SMF: single-mode fiber; TTM: time tagger module; WRS: White Rabbit Switch; PMF: polarization maintaining fiber; LPF: long-pass filter; PC: polarization controller.

Fig. 1 shows a schematic of our experimental setup. Fig. 1a shows the fiber route between two buildings on the NIST Gaithersburg campus. The source (middle pane Fig.1b) is located between Alice and Bob and is based on a periodically poled Potassium titanyl phosphate (ppKTP) waveguide crystal emitting photon pairs in the telecom C-band to reduce fiber absorption loss. The photons are coupled into a polarization-maintaining single-mode fiber to compensate for any temporal walk-off between the signal and idler photons. Dense wavelength division multiplexing (DWDM) is used to separate the signal and idler signals and send the polarization entangled state to the receivers of distant nodes at Alice and Bob [2]. The polarization entangled state occupies the DWDM ITU channels 29 (1553.33 nm) (Alice) and 30 (1554.13 nm) (Bob), respectively. Each receiver consists of a half-wave plate (HWP), a quarter-wave plate (QWP), a polarizer and a superconducting single-photon detector (SNSPD). Both receivers are synchronized using a

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pair of White Rabbit switches (WRSs). Alice locks to the WRS grandmaster (GM) clock output which is disciplined by a Rb frequency standard. Bob's WRS acts as a boundary clock (BC). Both WRSs are used to synchronize and calibrate the time base of the time tagger modules. Also, the local WRS time is used to retrieve time tags from the time tagging modules at a specified time. The WRSs at Alice and Bob transmit the HA-PTP at 1490 nm and 1310 nm, respectively, over 1 Gbps Ethernet using the same fiber as the quantum signal from our entangled photon source. A series of coarse wavelength division multiplexers (CWDMs) are used to multiplex and demultiplex the HA-PTP with the quantum signal. Further, a selectable DWDM filters the noise, and passes photons in the quantum channel's frequency band to the receiver. We find the additional noise in the quantum channel caused by the HA-PTP signal is about 4,500 (3,000) noise photons per second at Alice's (Bob's) receiver.

3. Results

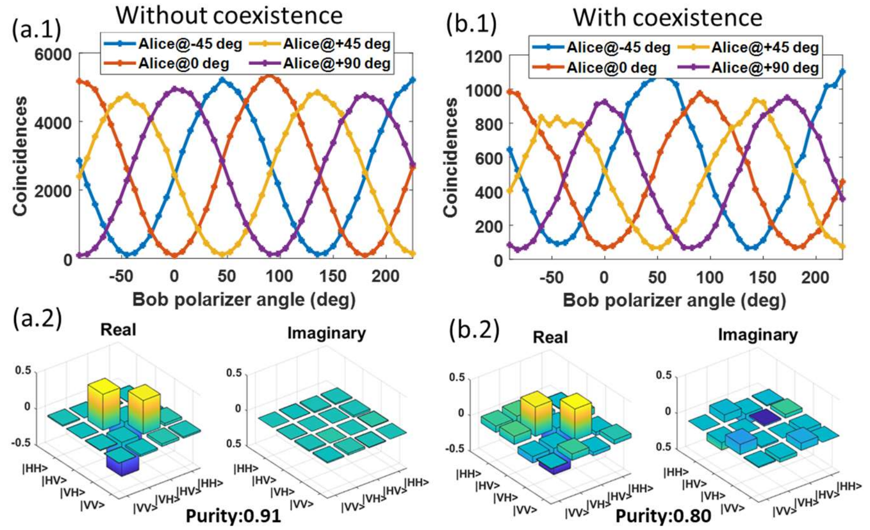

Figure 2. Experimental Results. (a.1) [(b.1)] Polarization entanglement fringes as measured without [with] the additional HA-PTP signal in the quantum fiber (2 s integration time). (a.2) [(b.2)] Tomography of polarization entangled state without [with] the additional HA-PTP signal in the quantum fiber.

Fig. 2a.1 shows polarization entanglement visibility fringes as obtained with Alice's HWP fixed at -22.5°, 0°, +22.5° and 45° (choosing the measurement basis along -45°, 0°, +45° and 90°) and by rotating Bob's HWP with only the quantum signal in the fiber. Therefore, CWDM and selectable filters were not used since there is no classical signal to filter. Fig. 2b.1 shows the entanglement fringes for the polarization entangled state when the quantum signal is coexisting in the same fiber along with the HA-PTP signal. The overall coincidence rate was reduced by a factor of 5 due to the high insertion loss of the 4 CWDMs and two selectable DWDM filters at each receiver. Nevertheless, we were able to measure entanglement fringe visibilities of 0.89, 0.87, 0.86 and 0.89 for the measurements bases of -45°, 0°, +45° and 90°, respectively. This compares to visibilities of 0.96, 0.97, 0.96 and 0.96 for the measurement without the HA-PTP signal. Fig. 2a.2 (2b.2) shows the tomographic reconstruction of the density matrix and a state purity of 0.91 (0.80) with (without) the additional HA-PTP signal in the quantum fiber.

Our results show that, while additional noise is present from HA-PTP, the co-existence of quantum entanglement distribution with picosecond level classical time synchronization remains feasible between two quantum network nodes separated by approximately 250 m.

Our results show that the coexistence of a classical HA-PTP for picosecond level synchronization of distant nodes and quantum signals for entanglement distribution in the same optical fiber is possible. The entanglement visibility reduction with classical time synchronization co-existence is due to a combination of the additional channel loss and extra noise. In the future, we will work on low-loss (de)multiplexing schemes and background reduction to further improve the entanglement fringe visibility.

4. References

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[2] Kaiser, Florian, et al., New Journal of Physics 14.8, 085015 (2012).

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