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A Telecom Infrastructure Compatible Quantum Link Using NV-centers

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Abstract: We show the latest progress towards establishing a solid-state, metropolitan quantum link, consisting of two remote Nitrogen Vacancy (NV)-centers and a central measurement station. The entanglement is generated by converting single emitted photons to the same frequency in the telecom L-band, guiding them to a central beamsplitter, where a joint Bell-state measurement projects the NV-centre spins in an entangled state. © 2023 The Author(s)

Introduction

A future quantum internet [1], built using quantum processor nodes connected via optical channels, holds the promise of fundamentally new applications. The task of creating, propagating and interfering single, indistinguishable photons is a central task in these networks. Spectral differences between nodes and incompatibility with propagation over telecom fibre infrastructure are two large challenges in scaling solid-state nodes beyond a few kilometers.In previous work, we employed two independently operated quantum network nodes on different optical tables [2], connected to a central midpoint. Here the light at the natural emission of 637 nm is converted to 1588 nm via a single-step Difference Frequency Generation (DFG) process, located in the telecom L-band. The successful interference of single photons is a necessary requirement for entanglement swapping using a central Bell-state measurement. Building on this earlier work, we report on first results on entanglement generation using NV centers via telecom photon heralding in the lab and share the latest results on a metropolitan-scale demonstration.

Results

We employ a single click entanglement generation scheme similar to earlier experiments [3,4], which allows for a higher rate of entanglement generation. This is due to the rate only being linearly affected by photon loss, at the cost of higher experimental complexity because of stringent phase requirements. Several experimental improvements have been realized to stabilize the optical phase between the network nodes. First we added analog signal processing and control electronics to both nodes and the midpoint to stabilize the optical phase of the incoming single photons. These modifications allow us to stabilize the relevant noise sources effectively at all different timescales. Most importantly, it removes the fast phase noise introduced by using separate excitation lasers, a crucial requirement for large separation between end nodes.

Second, we improved the routing of the classical laser fields needed for the stabilization to better shield our single-photon detectors (SNSPDs) from being blinded. This greatly reduced the elevated noise counts reported in our earlier work [2], allowing us to operate at a higher repetition rate needed for the phase stabilization. Furthermore, it improves the signal-to-noise ratio of the photons measured in our Bell-state measurement, the main limitation of both the quantum interference and resulting entanglement generation.

We verify the performance of our phase stabilization by reflecting bright pulses off the diamond surfaces, monitoring the interference contrast while sweeping the central interferometer phase setpoint, see figure 1. By normalizing the measured interference using the measured count rates from both nodes, we recover a high contrast of 0.84 ± 0.003, showing excellent phase stability and control over the optical fields.

Combining the improvements into one experiment, we were able to characterize the entanglement generation whilst the setups were in the same lab. Early results show an entangled state generated with a fidelity of 0.64 ± 0.01 with the ideal Bell-states, limited mainly by the signal-to-noise ratio in the SNSPDs. An extensive model containing many independently measured parameters [5] shows good agreement to our data.

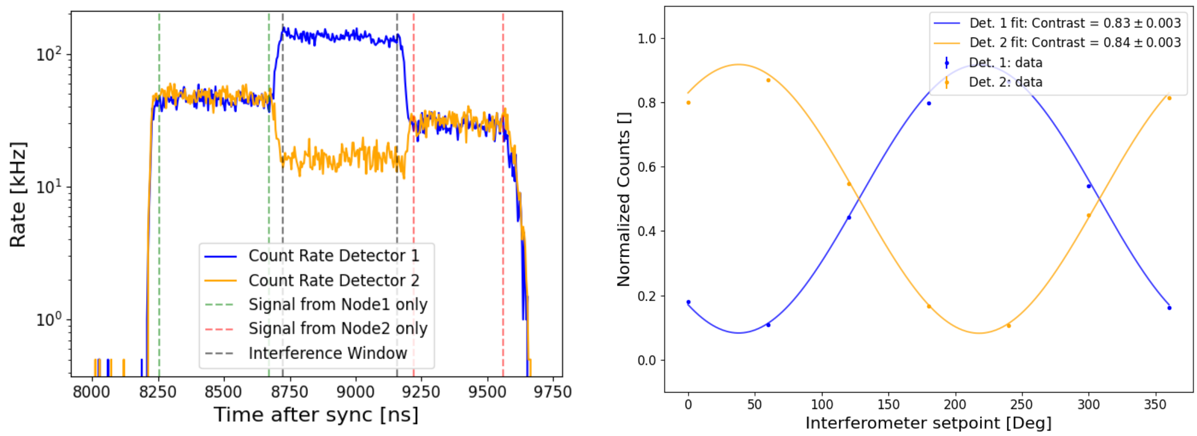

Fig. 1: **Measuring phase coherence** (left) Reflections from the excitation lasers on both nodes are send to the central beamsplitter, interfering at the regions where the fields overlap in time. By integrating the counts in the different regions, we can extract the normalized contrast. (right) By changing the interferometer setpoint to different phases, we can measure a full interference fringe, showing high contrast of 0.84 ± 0.003, confirming the phase coherence between the nodes

Conclusion

We have shown significant improvements towards the goal of generating a metropolitan quantum link using NV centers as end nodes. We verified the the design and implementation for long-range phase coherence of the optical fields, a crucial requirement for efficient entanglement generation. Most importantly, we verified our scheme by generating entanglement within the same lab, whilst operating in a way fully compatible with metropolitan scale entanglement generation.

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