Generating and teleporting entanglement for quantum networks

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Abstract

Entanglement is a key resource of future quantum technologies. For that reason, it will be essential to distribute it in quantum networks between many and possibly very distant communication parties. To this end, it is essential to generate the photons at a wavelength that is compatible with existing fiber network infrastructure. Such networks typically feature very low loss for photons in the O and C band (1310nm and 1550nm, respectively). To more efficiently use telecom fibers for many users, the available bandwidth is split into frequency windows to enable dense wavelength division multiplexing (DWDM). In the present thesis, we will implement a Sagnac source of entanglement for photons around 1560nm that is sufficiently narrowband for the entangled photons to fit into specific DWDM frequency channels. To generate the entangled photons, we will use a 50 mm long nonlinear crystal inside a Sagnac interferometer. We will first implement and characterize this source in our laboratory and later use it for demonstrating entanglement distribution over in an existing fiber network. The wavelength of the pump laser will be stabilized to an absorption line in a Rubidium gas cell. With our help, an identical source will be set up by partners at the Jozef Stefan Institute. This will allow us to demonstrate the teleportation of entanglement (entanglement swapping) by performing a Bell-state measurement on two entangled photons from those two independent and distant sources. This technique is a prerequisite for quantum repeaters, which will be essential to distribute entanglement over arbitrary long distances in future global quantum networks. In particular, even the low losses of photons in the C band will exponentially grow with the distance. This limits the efficient distribution of entanglement to distances of a few hundred kilometers. The present work will not only feature the first realization of a source of entanglement in Slovenia but also the first realization of teleportation.
Key words: Quantum Entanglement, Quantum Key Distribution, Entanglement Swapping

1 Contents and introduction

Today I will be speaking to you about my a part of my thesis, which is generating and teleporting entanglement for quantum networks. I will begin with a bit of theory, where I will explain the basics of the Spontaneous Parametric

Downconversion (SPDC). Here I will speak a bit about Phase Matching and how we try to optimize it in the lab. I will also speak a bit about how we plan on Distributing Entanglement, so Entanglement Teleportation and Swapping. Then I will speak about the present state that we are dealing with in the lab and how far we have gone so far.

2 Motivation

Pretty much the enterity of my project is in the scope of the SiQUID project. The goal of this project is to create a Slovenian Quantum Network, train young researchers in the field of Quantum Technologies, as well as creating the sources of entanglement needed for entanglement based Quantum Key Distribution. The main goal for me in this regard would be to create a bright source of entanglement using a Sagnac interferometer. The reason we chose a Sagnac in this case is due to its long term vibrational stability, and it's a convenient way to do so as it allows for a compact design. A possible downside to this is that the alignment of this type of interferometer is a bit tedious, as you have to perfectly overlap two beams within the interferometer, and in the crystal.

3 Theory

3.1 Spontaneous Parametric Downconversion

SPDC is a process in which a pump photon of frequency ω_p gets "downconverted" to two or more photons of lower frequency, usually denoted as ω_s and ω_i. These output photons can have the same frequency, and thus this can be a degenerate process, or they can have different frequencies, or being non-degenerate. When we started this entire design process, we wanted to have a degenerate process, as we would be able to separate the two photons based on their polarization. This design utilited a type-II process, meaning that we would be able to separate the two photons on the output of the PBS. There are also type-I and type-0 processes. In type-I the output photons are orthogonal to the pump photon, while in the type-0 process the pump and output photons have the same polarization.

3.2 Types of processes

There are three different types of processes.

- Type-0 is one in which a photon of some linear polarization, say $|H\rangle$ gets downconverted into two photons of lower energies of the same polarization - o $\rightarrow$ o + o. This process used to be physically impossible to produce as the phase matching condition $k_1 + k_2 = k_3 = \frac{n\omega_3}{c} = \frac{n\omega_1}{c} + \frac{n\omega_2}{c}$ is impossible to achieve in most cases.
- Type-I is similar to type-0, except that the produced two photons are orthogonally polarized to the input photon - o $\rightarrow$ e + e

- In type-II instead you get two orthogonal polarizations out from the crystal. e $\rightarrow$ e + o

3.3 Crystals

The first important step is to choose the correct material for the job. In this case, no ordinary material can be used, as the phase matching condition $k_1 + k_2 = k_3 = \frac{n\omega_3}{c} = \frac{n\omega_1}{c} + \frac{n\omega_2}{c}$ is impossible to satisfy in most cases as $n_1(\omega_1) < n_2(\omega_2) < n_3(\omega_3)$ for $\omega_1 < \omega_2 < \omega_3$.

3.4 Phase Matching

What is Phase Matching?