Photonic Quantum Network Links and Nodes

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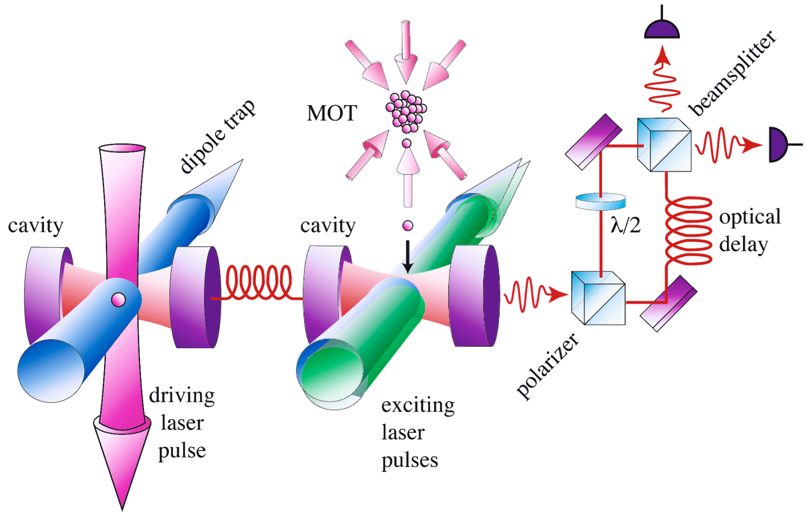
Quantum information processing in photonic networks is based on single photons that carry information between network nodes, which represent themselves quantum gates or memories. All-optical quantum-information processing seems feasible with nodes in form of linear optical elements [1], and storage and retrieval of qubits in individual nodes could be accomplished by isolated single atoms acting as quantum memories [2], or by the use of dark-state polaritons in atomic ensembles [3]. All these schemes require mutually coherent single photons, which are not obtained from most single-photon emitters. Only recently, elaborate photon-emission techniques from a quantum dot have been demonstrated and it has been shown that these are well suited for applications where a single emitter is sufficient [4]. However, most quantum dots differ from each other, which hampers scaling to larger devices. Moreover, all photon sources that employ short-lived quantum states cannot operate as quantum memories since they are unable to receive a photon and map its state to long-lived quantum states of another well-defined system.

Our work is focussed on the experimental demonstration of some elementary quantum-network links and nodes. Narrow-band single photons are obtained from a strongly coupled atom-cavity system that employs a controlled energy exchange between the atom and the quantized light field of the cavity [5, 6]. This is accomplished by laser pulses adiabatically driving one branch of a Raman transition in a Λ-type three-level atom, which is located in a high-finesse optical cavity resonant with the other branch of the transition [7, 8]. The transition goes hand-in-hand with a change of the photon number in the cavity. This process is unitary and therefore intrinsically reversible, so that it should allow one to map the state of an atom to a photon and vice versa, which is the starting point for distributed quantum networking of coupled atom-cavity systems.



Artist's view of a possible rudimentary quantum network combining single-photon emitters and receivers (on the left), and a two-photon interferometer (on the right), which is using an optical fiber as delay line to superpose successively emitted photons on a beamsplitter.

Currently, we investigate the feasibility of all-optical quantum information processing based on second-order interference of indistinguishable photons, with qubits encoded in photon number states. To this purpose, we study two-photon interference phenomena [9] with pairs of photons successively emitted from the atom-cavity system. The first photon is delayed so that it impinges on a beamsplitter together with the second photon. These simultaneously arriving photons give rise to a dip in the cross-correlation function of the two photodetectors monitoring the output ports of the beamsplitter. Note that a similar behaviour has been observed by C. Santori et al. [4] with photons being successively emitted from a single quantum dot. Moreover, we are working on a quantum register, which is designed to allow quantum processing and quantum networking experiments with atoms held at rest inside a high-finesse cavity by means of an optical dipole force trap. The state-of-the-art of this project is shown, and we will discuss how to combine all the different elements to a scalable quantum network that can be used for information processing.

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