Transfer of an unknown quantum state, quantum networks, and memory

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We present a protocol for transfer of an unknown quantum state. The protocol is based on a two-mode cavity interacting dispersively in a sequential manner with three-level atoms in the \( \Lambda \) configuration. We propose a scheme for quantum networking using an atomic channel. We investigate the effect of cavity decoherence in the entire process. Further, we demonstrate the possibility of an efficient quantum memory for arbitrary superposition of two modes of a cavity containing one photon.

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I. INTRODUCTION

In the quantum information theory [1], transfer of information in the form of a coherently prepared quantum state is essential. One can transfer a quantum state either by the method of teleportation [2] or through quantum networking. The basic idea behind a quantum network is to transfer a quantum state from one node to another node with the help of a career (a quantum channel) such that it arrives intact. In between, one has to perform a process of quantum state transfer (QST) to transfer the state from one node to the career and again from the career to the destination node. There have been some proposals [3] for quantum networking using cavity-QED, where two atoms trapped inside two spatially separated cavities serve the purpose of two nodes. In Ref. [3], the task was to transfer the state of one atom into the other via the process of QST between the atom and photon, where the latter is used as a career. The photon carries the information through either free space or an optical fiber between the cavities, and the success depends on the probabilistic detection of photons or adiabatic passage through the cavities. We note that, though it may be difficult to beat the direct spin interaction of the \( \hat{S}_{1} - \hat{S}_{2} \) kind, the quantum state could be transferred from one atom to another within a microscopic range. In the present scheme, we show how a similar kind of interaction between two atoms can be mediated via a cavity. Thus the atomic state can be transferred from one atom to another in the mesoscopic range.

We extend our idea of QST to a quantum network, where we transfer the state of one cavity to another spatially separated cavity. For this we use long-lived atoms as career, and make use of the QST process to transfer the state of the cavity to an atom and again to the target cavity. Our protocol for quantum networking provides a deterministic way to transfer the quantum state between the cavities. This protocol does not require any kind of probability arguments based on the outcome of a measurement. Further, we propose the realization of a quantum memory of arbitrary superposition of two modes of a cavity which contains only one photon. This superposition state can be stored in the long-lived states of the neutral atoms and retrieved in another two-mode cavity later, deterministically. Our proposal relies on the technological advances and realizations as described in Ref. [10].

The structure of the paper is as follows. In Sec. II, we describe the model and provide the relevant equations. In Sec. III, we discuss how transfer of an unknown quantum state can be performed between two atoms. We provide an estimate of possible decoherence in this process due to cavity decay. In Sec. IV, we extend our scheme to quantum networks and quantum memory.

II. MODEL CONFIGURATION

To describe how the QST protocol works, we consider a three-level atom in the \( \Lambda \) configuration interacting with a two-mode cavity (see Fig. 1). The modes with annihilation operators \( a \) and \( b \) interact with the |e\rangle \leftrightarrow |g\rangle and |e\rangle \leftrightarrow |f\rangle transitions, respectively. The Hamiltonian under the rotating wave approximation can be written as...