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Quantum state transfer via the selective pairing of off-resonant Raman transitions

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Abstract. A simple scheme for transferring an unknown atomic state based on the pairing of off-resonant Raman transitions is proposed. The scheme is insensitive to the atomic spontaneous emission, cavity decay, and fiber decay. Meanwhile, in the scheme, operations between any pair of atomic qubits and selective parallel two-qubit operations on different qubit pairs can be implemented. The atoms, the cavity modes and the fiber are not excited during the operations. A quantum communication network for transferring quantum information can be established. Therefore the scheme would be a useful step toward future scalable quantum computing networks.

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Key words: transfer, off-resonant Raman transitions, separate cavities

1 Introduction

Quantum state transfer (QST), which is an important part of quantum information processing such as quantum teleportation [1,2], quantum dense coding [3], quantum cryptography [4], and quantum computer[5] etc. has attracted much attention. It is a process of transferring a quantum state from one node to another node with the help of a career (a quantum channel).In recent years,a great many of QST protocols have been presented in various quantum systems [6-13]. For example, Yang *et al.* [6, 7] presented two different schemes for transferring of quantum state with superconducting quantum interference device qubits in cavity QED. Christandl *et al.* [8] presented a QST scheme through quantum network using a linear XY chain of N interacting qubits. Quantum state transfer between two atoms in a cavity has been demonstrated via resonant interaction[9]. Cirac

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et al. proposed a QST scheme [10] between two atoms trapped inside two spatially separated cavities via an optical fiber in cavity quantum electrodynamics(cavity QED). Biswas *et al.* [11] presented a QST proposal based on two-mode cavity interacting dispersively with three-level atoms in the configuration. Ye *et al.* [12,13] proposed some schemes for transferring of two-mode entangled state and unknown atomic entangled state via cavity QED. Among the different quantum systems, cavity QED system is always considered as the most effective system due to its ability of constructing quantum networking [14] and low decoherent rate[15].Recently, the system of separate cavities connected by optical fibers have been attracted more and more attention in quantum information processing such as entanglement preparation, QST *et al.*[16–22]. Zheng [16] proposed an efficient scheme for quantum communication between two atoms trapped in distant cavities which are connected by an optical fibre. Pellizzari *et al.* [17] proposed a scheme of transferring quantum information between two distant $\wedge$-type atoms via an adiabatic passage in a cavity-fiber-cavity system. Yin *et al.* [18] proposed a QST scheme between two remote coupled systems of cavity-atom. However, to the best of our knowledge, the most of previous QST schemes are two-dimension schemes of transferring quantum information between two qubits, and there are few schemes to consider how to realize entangled state QST between two atom pairs trapped in separate cavities linked by optical fibers.

In this paper we present a simple QST scheme between two atom pairs trapped in separate cavities linked by optical fibers based on the pairing of off-resonant Raman transitions. In the scheme two ground states of each atom are coupled via the respective cavity mode and a classical field in the Raman manner. Under the large detuning condition, the atoms do not undergo real Raman transitions and the Hamiltonian for the atomic system is decoupled from the cavity modes and fiber mode. The quantum state is mediated by the vacuum fields.

In the conventional two-dimensional (2D) QST schemes, the transferred quantum information is coded in such state $\alpha|0\rangle+\beta|1\rangle$. But in our QST scheme, the transferred quantum information is coded in such state $\alpha|0\rangle1\rangle_{12}+\beta|1\rangle|0\rangle_{12}$. Therefore, the transferred quantum information in our QST schemes is more secure than that in the 2D QST schemes. In addition, there are more information carriers in the present QST scheme, and hence more abundant information can be transferred based on the present QST scheme. Therefore, the present QST scheme motivates the current work due to its inherent advantage compared to 2D QST. In addition, our scheme has the following advantages:

(i) The scheme is insensitive to the atomic spontaneous emission, cavity decay, and fiber decay.

(ii) In the scheme, the Raman transitions of each qubit only can be coupled to those of selected qubits to produce the desired qubit-qubit interaction.

(iii) In our scheme, the operations between any pair of atomic qubits can be implemented without exciting both the atoms and the field modes, thus our scheme