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Scheme for implementing quantum information sharing via tripartite entangled state in cavity QED

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Abstract

We investigate economic protocol to securely distribute and reconstruct a single-qubit quantum state between two users via a tripartite entangled state in cavity QED. Our scheme is insensitive to both the cavity decay and the thermal field.

Keywords: Quantum information sharing; Tripartite entangled state; Cavity QED

1. Introduction

Entanglement is one of the most counterintuitive features in quantum mechanics; assisted with entangled state one can complete many impossible tasks within the classical world. One of the most striking applications of entanglement is quantum secret sharing (QSS) [1]. It is a process to distribute private key among three [1] or multiple parties [1,2] securely. If and only if when they cooperate, they can get complete information about the message. Meanwhile, if one of them is dishonest, the honest players may keep the dishonest one from doing any damage. But, up to now, most existing QSS schemes only focused on creating a private key or splitting a classical secret among many parties. Recently, due to its promising applications in quantum secure communication, it attracts many attentions. However, many applications in quantum information theory require the distribution of quantum states. Cleve et al. [3] proposed a protocol providing robust and secure distribution of quantum states between nodes, which Lance et al. [4] termed as *quantum state sharing* to differentiate from the QSS of classical information. As quantum state carries quantum information, it is also called *quantum information sharing* (QIS). Quantum state sharing is a protocol where perfect reconstruction of quantum state is achieved with partial information of a multipartite quantum network. It also allows for secure communication in a quantum network where partial information is lost or acquired by disloyal parties.

Recently, Lance et al. demonstrated schemes for encoding a secret coherent state into a tripartite entangled state and distributing it to two players both theoretically [4] and experimentally [5]. Deng et al. [6] proposed a scheme for multiparty quantum state sharing of an arbitrary two-particle entanglement with EPR pairs.

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Li et al. [7] investigated protocol for multiparty secret sharing of single-qubit quantum information. In the previous schemes, Bell state measurements (in Ref. [6]) or even multipartite joint measurements (in Ref. [7]), which is still under extensive research among many ambitious scientists, are widely employed. Zhang et al. [8], proposed a scheme for QIS of a single-qubit state based on entanglement swapping in cavity QED where the effects of cavity decay and thermal field are both eliminated. However, in quantum information theory, entangled states are precious resource, thus one should employ them with great deliberation. In Ref. [8], they utilize an EPR and tripartite GHZ state (five atomic qubits) to finish the task of a single-qubit state sharing between two parties while four qubits (two EPR states) can complete the task [6]. Furthermore Ref. [1] showed that three qubits (a pure tripartite entangled GHZ type state) is sufficient.

It is well known that multipartite qubits can be entangled in different inequivalent ways. For tripartite entangled quantum system, it falls into two classes of irreducible entanglements [9], that is, GHZ and W class state. The motivation of classifying entangled state is that, if the entanglement of two states is equivalent, then the two states can be used to perform the same task, although the probability of successful performance of the task may depend on the amount of entanglement of the state. But, in the branch of quantum state sharing, as well as in QSS, most of the previous schemes [1–8] utilize the GHZ class of entangled state. W class state is also a promising candidate in implementing quantum communication and other tasks in the realm of quantum information processing. Recently, Joo et al. [10] presented a novel scheme for secure quantum communication via W state, where they proposed three different protocols for secure quantum communication, that is, quantum key distribution, probabilistic QSS of classical information and their synthesis. In order to extensively investigate the applications of W class states in quantum communication, we engage ourselves in the work of implementing quantum state sharing via W class state in this paper. Here, we first investigate a physical scheme for Ref. [1] in cavity QED, which shares single-qubit quantum state via a tripartite GHZ state. Then we will argue that W class state can also fulfill the task probabilistically. The distinct advantage of the scheme is that during the passage of the atoms through the cavity field, a strong classical field is accompanied, thus our scheme is insensitive to both the cavity decay and the thermal field.

2. The cavity model

We consider two identical two-level atoms simultaneously interacting with a single-mode cavity and driven by a classical field. Then the interaction between the single-mode cavity and the atoms can be described, in the rotating-wave approximation, as [11]

$$H = \omega_0 S_Z + \omega_a a^+ a + \sum_{j=1}^{2} [g(a^+ S_j^- + a S_j^+) + \Omega(S_j^+ \mathrm{e}^{-\mathrm{i}\omega t} + S_j^- \mathrm{e}^{\mathrm{i}\omega t})], \tag{1}$$

where $S_Z = \frac{1}{2}\sum_{j=1}^{2}(|e\rangle_{j,j}\langle e| - |g\rangle_{j,j}\langle g|)$, $S_j^+ = |g\rangle_{j,j}\langle e|$, $S_j^- = |e\rangle_{j,j}\langle g|$ and $|e\rangle_j$, $|g\rangle_j$ are the excited and ground states of jth atom, respectively. a^+ and a are the creation and annihilation operators for the cavity mode, respectively. g is the coupling constant between atomic system and the cavity, Ω is the Rabi frequency, ω_0 , ω_a and ω are atomic transition frequency, cavity frequency and the frequency of the driven classical field, respectively.

While in the case of $\omega_0 = \omega$, in the interaction picture, the interaction Hamiltonian is

$$H_I = \Omega \sum_{j=1}^{2} (S_j^+ + S_j^-) + g \sum_{j=1}^{2} (\mathrm{e}^{-\mathrm{i}\delta t} a^+ S_j^- + \mathrm{e}^{\mathrm{i}\delta t} a S_j^+), \tag{2}$$

where δ is the detuning between atomic transition frequency ω_0 and the cavity frequency ω_a.

We define the new atomic basis

$$|+\rangle_j = \frac{1}{\sqrt{2}}(|g\rangle_j + |e\rangle_j), |-\rangle_j = \frac{1}{\sqrt{2}}(|g\rangle_j - |e\rangle_j). \tag{3}$$