Vol 15 No 8, August 2006
1009-1963/2006/15(08)/1695-05

Chinese Physics

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Protocol for multi-party superdense coding by using multi-atom in cavity QED*

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(Received 16 September 2005; revised manuscript received 28 April 2006)

We present a protocol for multi-party superdense coding by using multi-atom in cavity quantum electrodynamics (QED). It is shown that, with a highly detuned cavity mode and a strong driving field, the protocol is insensitive to both cavity decay and thermal field. It is even certain to identify GHZ states via detecting the atomic states. Therefore we can realize the quantum dense coding in a simple way in the multiparty system.

Keywords: dense coding, cavity QED
PACC: 0365, 4250

1. Introduction

The quantum entanglement state[1−2] is an important tool to distinguish the quantum mechanics from the classical physics. In quantum information processing, there are many useful applications of entangled states such as quantum dense coding,[3] quantum teleportation[4] and quantum cryptography.[5] Here we focus on quantum dense coding. Normally the classical capacity of the transmission channel is one bit; however, in dense coding, with the help of entanglement, two bits can be transmitted by sending only one quantum bit (qubit). Two-particle quantum dense coding has been experimentally demonstrated by using optical systems and techniques of nuclear magnetic resonance.[6−8] Recently, a lot of dense coding schemes including applications have been considered by many authors. But the decoherence of the cavity field is still one of the main obstacles to the implementation of quantum information in cavity quantum electrodynamics (QED). In Ref.[9], Zheng proposed a scheme where atoms interact simultaneously with a highly detuned cavity mode with the assistance of a classical field. The scheme is insensitive to the cavity decay and the thermal field. Following this idea, Ye and Guo proposed a scheme[10] to implement quantum dense coding for two two-level atoms via cavity QED. However, only two-particle dense coding case was studied.

Recently, preparation[9,11] and applications[12,13] of multipartite entangled states are a hot topic in the field of quantum information. It has been shown that multiparticle states have many advantages over the two-particle Bell states in quantum cloning,[14,15] quantum teleportation[16] and superdense coding.[17] In this paper, we generalize the scheme of dense coding[10] to multiparty system by considering the interaction of $N+1$ two-level atoms in cavity QED. The distinct advantage[10] of the protocol is that during the passage of the atoms through the cavity field, a strong classical field is accompanied so that the photon-number-dependent parts are cancelled. Thus the scheme is insensitive to both cavity decay and the thermal field. More importantly, 2^{N+1} GHZ states can be exactly identified by detecting atoms separately. Thus, the complexity of GHZ-state measurement is reduced.

2. Model

First we consider k identical two-level atoms simultaneously interacting with a single-mode quantum cavity field and driven by a classical field. In the strong driving regime $2\Omega \gg \delta$, g and in the case $\delta \gg g/2$ (Ω is the Rabi frequency of the classical field, g is the atoms-cavity coupling strength and δ is the detuning between the atomic transition frequency and the cavity field frequency), there is no energy exchange between the atomic system and the cavity. In

*Project supported by the National Natural Science Foundation of China (Grant No 10374025).
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the interaction picture, the effective Hamiltonian can be described as follows:[9,10]

$$\begin{aligned} H_{\rm eff} =& H_0 + H_{\rm e}, \\ H_0 =& \Omega \sum_{j=1}^{k} (S_j^+ + S_j^-), \\ H_{\rm e} =& \lambda [\frac{1}{2} \sum_{j=1}^{k} (|e_j\rangle\langle e_j| + |g_j\rangle\langle g_j|) \\ &+ \sum_{j,l=1}^{k} (S_j^+ S_l^+ + S_j^+ S_l^- + \text{H.C.})], \quad j \neq l, \end{aligned} \tag{1}$$

where $\lambda = g^2/2\delta$, $S_j^+ = |e_j\rangle\langle g_j|$, $S_j^- = |g_j\rangle\langle e_j|$, with $|e_j\rangle$ and $|g_j\rangle$ $(j = 1, 2, \cdots, k)$ being the excited and ground states of the jth atom. Here we have assumed that the transition frequency of atoms is equal to the frequency of classical field. We note that the effective Hamiltonian is independent of the cavity field state, allowing it to be in a thermal state. The effective Hamiltonian $H_{\rm eff}$ can also be rewritten as

$$H_{\rm eff} = 2(\Omega S_x + \lambda S_x^2), \tag{2}$$

where $S_x = \frac{1}{2} \sum\limits_{j=1}^{k} (S_j^+ + S_j^-)$. Then the evolution operator of the system is given by

$$U(t) = \mathrm{e}^{-\mathrm{i}H_{\rm eff}t} = \mathrm{e}^{-\mathrm{i}2(\Omega S_x + \lambda S_x^2)t}. \tag{3}$$

Using the representation of the operator S_z, the atomic states $|g_1 g_2 \cdots g_k\rangle$ and $|e_1 e_2 \cdots e_k\rangle$ can be expressed as $|k/2, -k/2\rangle$ and $|k/2, k/2\rangle$, respectively. On the other hand, such states can be expanded in terms of the eigenstates of S_x[18−20] as follows:

$$|k/2, -k/2\rangle = \sum_{M=-k/2}^{M=k/2} C_M |k/2, M\rangle_x, \tag{4}$$

$$|k/2, k/2\rangle = \sum_{M=-k/2}^{M=k/2} C_M (-1)^{k/2-M} |k/2, M\rangle_x. \tag{5}$$

We assume that the atoms are initially in the state $|g_1 g_2 \cdots g_k\rangle$. The evolution of the system is

$$\sum_{M=-k/2}^{M=k/2} C_M \mathrm{e}^{-2\mathrm{i}(\Omega M + \lambda M^2)t} |k/2, M\rangle_x. \tag{6}$$

When k is even, M is an integer, with the choice $\lambda t = \pi/4$ and $\Omega t = n\pi$ we obtain

$$\begin{aligned} &\frac{1}{\sqrt{2}} \sum_{M=-k/2}^{M=k/2} C_M [\mathrm{e}^{-\mathrm{i}\pi/4} \\ &+ \mathrm{e}^{\mathrm{i}\pi/4} (-1)^M] |k/2, M\rangle_x \\ =& \frac{1}{\sqrt{2}} [\mathrm{e}^{-\mathrm{i}\pi/4} |g_1 g_2 \cdots g_k\rangle \\ &+ \mathrm{e}^{\mathrm{i}\pi/4} (-1)^{k/2} |e_1 e_2 \cdots e_k\rangle]. \end{aligned} \tag{7}$$

On the other hand, for the case where k is odd we chose $\lambda t = \pi/4$ and $\Omega t = (2n + 3/4)\pi$. Then we obtain

$$\begin{aligned} &\frac{1}{\sqrt{2}} \mathrm{e}^{\mathrm{i}(7/8)\pi} [\mathrm{e}^{-\mathrm{i}\pi/4} |g_1 g_2 \cdots g_k\rangle \\ &+ \mathrm{e}^{\mathrm{i}\pi/4} (-1)^{(1+k)/2} |e_1 e_2 \cdots e_k\rangle]. \end{aligned} \tag{8}$$

If the k atoms are initially in the state $|g_1 \cdots g_i e_{i+1} \cdots e_j g_{j+1} \cdots g_k\rangle$, from Eqs.(2), (3), (6) and (7), we obtain the following evolution:

$$\begin{aligned} |g_1 \cdots g_i e_{i+1} \cdots e_j g_{j+1} \cdots g_k\rangle \xrightarrow{U(t)} & \frac{1}{\sqrt{2}} [\mathrm{e}^{\mathrm{i}\pi/4} (-1)^{k/2} |e_1 \cdots e_i g_{i+1} \cdots g_j e_{j+1} \cdots e_k\rangle \\ &+ \mathrm{e}^{-\mathrm{i}\pi/4} |g_1 \cdots g_i e_{i+1} \cdots e_j g_{j+1} \cdots g_k\rangle], \end{aligned} \tag{9}$$

with k is even ($\lambda t = \pi/4$, $\Omega t = n\pi$), and

$$\begin{aligned} |g_1 \cdots g_i e_{i+1} \cdots e_j g_{j+1} \cdots g_k\rangle \xrightarrow{U(t)} & \frac{1}{\sqrt{2}} \mathrm{e}^{\mathrm{i}(7/8)\pi} [\mathrm{e}^{\mathrm{i}\pi/4} (-1)^{(k+1)/2} |e_1 \cdots e_i g_{i+1} \cdots g_j e_{j+1} \cdots e_k\rangle \\ &+ \mathrm{e}^{-\mathrm{i}\pi/4} |g_1 \cdots g_i e_{i+1} \cdots e_j g_{j+1} \cdots g_k\rangle], \end{aligned} \tag{10}$$

with k is odd ($\lambda t = \pi/4$, $\Omega t = 2n\pi + 3/4\pi$).

3. Superdense coding

Now, we present our scheme for dense coding between multiparties. There are $N+1$ users sharing an $(N+1)$-particle state $|g_1g_2\cdots g_Ne_{N+1}\rangle$, possessing one particle each. Suppose that one of them, say user $N+1$, intends to receive messages from the other N users. Firstly, we let the $N+1$ atoms interact simultaneously with a single-mode cavity, at the same time are driven by a classical field. The state evolution of the system is described by Eq.(3). Now we consider the following two cases ($N+1$ is even or odd).

Case I where $N+1$ is even. With the choice of $\lambda t=\pi/4$ and $\Omega t=n\pi$, the whole state evolves to the maximally $(N+1)$-atom entangled state

$$|\psi_0\rangle =\frac{1}{\sqrt{2}}(|g_1g_2\cdots g_Ne_{N+1}\rangle + \mathrm{i}(-1)^{\frac{N+1}{2}}|e_1e_2\cdots e_Ng_{N+1}\rangle). \tag{11}$$

To realize the quantum dense coding, the N senders mutually decided a priori to perform only certain unitary operations on their particles. User 1 can perform all the 4 one-body operations $\{I,\sigma^x,\mathrm{i}\sigma^y,\sigma^z\}$ (where I is the identity operator and σ^i are three Pauli operators), and user 2 through user N can only perform the 2 one-body operations $\{\sigma^x,\sigma^z\}$. Then the N users can encode their messages by performing their allowed operations on the particles at their disposal and return the particles to user $N+1$. The N senders are allowed to perform $2^2\times 2\times\cdots\times 2=2^{N+1}$ different combinations of the one-body unitary operations on the $(N+1)-$particle maximally entangled state in Eq.(10). There are 2^{N+1} unitary operators to map the state in Eq.(10) to different GHZ states. In this case user $N+1$ possesses $N+1$ atoms. Now what user $N+1$ wants to do is know how to identify the 2^{N+1} states.

User $N+1$ lets $N+1$ atoms simultaneously interact with another single-mode cavity and at the same time $N+1$ atoms are driven by a classical field. The system evolution is described by Eq.(3). If we choose the interaction time τ and Rabi frequency Ω appropriately so that $\lambda\tau=\pi/4$, $\Omega\tau=n\pi$, the different GHZ states will be orthogonal states $|g_1g_2\cdots g_Ng_{N+1}\rangle$, $|g_1g_2\cdots g_Ne_{N+1}\rangle$, $\cdots$, $|e_1e_2\cdots e_Ng_{N+1}\rangle$, $|e_1e_2\cdots e_Ne_{N+1}\rangle$ in the Hilbert space of $N+1$ particles. Hence, the GHZ-state measurement can be achieved by detecting atoms $1,2,\cdots,N+1$ separately. User $N+1$ can read out $N+1$ bits of classical information after performing a measurement on each joint state of the $N+1$ qubits.

To present our scheme more clearly, now we consider four-party ($N+1=4$) dense coding. Assume that four atoms are initially in the state $|g_1g_2g_3e_4\rangle$. The four atoms are simultaneously sent into the cavity discussed above. With the choice of $\lambda t=\pi/4$ and $\Omega t=\pi$, we obtain the maximally four-atom entangled state from Eq.(10) as follows:

$$\frac{1}{\sqrt{2}}(|g_1g_2g_3e_4\rangle+\mathrm{i}|e_1e_2e_3g_4\rangle). \tag{12}$$

To realize the quantum dense coding, user 1 performs one of the four local operations $\{I,\sigma^x,\mathrm{i}\sigma^y,\sigma^z\}$ on his atom 1, user 2 and user 3 can perform one of the two operators $\{\sigma^x,\sigma^z\}$ on their atoms. Through simple calculation, it can be shown that the $4\times 2\times 2=16$ different unitary operators

$$\begin{aligned}
U_0 =&I\otimes\sigma^z\otimes\sigma^z,\quad U_1=I\otimes\sigma^z\otimes\sigma^x, U_2=I\otimes\sigma^x\otimes\sigma^x,\quad U_3=I\otimes\sigma^x\otimes\sigma^z,\\
U_4 =&\sigma^x\otimes\sigma^z\otimes\sigma^z,\quad U_5=\sigma^x\otimes\sigma^z\otimes\sigma^x, U_6=\sigma^x\otimes\sigma^x\otimes\sigma^x,\quad U_7=\sigma^x\otimes\sigma^x\otimes\sigma^z,\\
U_8 =&\sigma^z\otimes\sigma^z\otimes\sigma^z,\quad U_9=\sigma^z\otimes\sigma^z\otimes\sigma^x, U_{10}=\sigma^z\otimes\sigma^x\otimes\sigma^x,\quad U_{11}=\sigma^z\otimes\sigma^x\otimes\sigma^z,\\
U_{12} =&i\sigma^y\otimes\sigma^z\otimes\sigma^z,\quad U_{13}=i\sigma^y\otimes\sigma^z\otimes\sigma^x, U_{14}=i\sigma^y\otimes\sigma^x\otimes\sigma^x,\quad U_{15}=i\sigma^y\otimes\sigma^x\otimes\sigma^z
\end{aligned} \tag{13}$$

will transform the state $|\psi_0\rangle$ into the following states, respectively:

$$\begin{aligned}
&U_0|\psi_0\rangle=|\psi_0\rangle=\frac{1}{\sqrt{2}}(|g_1g_2g_3e_4\rangle+\mathrm{i}|e_1e_2e_3g_4\rangle, U_1|\psi_0\rangle=|\psi_1\rangle=\frac{1}{\sqrt{2}}(|g_1g_2e_3e_4\rangle-\mathrm{i}|e_1e_2g_3g_4\rangle,\\
&U_2|\psi_0\rangle=|\psi_2\rangle=\frac{1}{\sqrt{2}}(|g_1e_2e_3e_4\rangle+\mathrm{i}|e_1g_2g_3g_4\rangle, U_3|\psi_0\rangle=|\psi_3\rangle=\frac{1}{\sqrt{2}}(|g_1e_2g_3e_4\rangle-\mathrm{i}|e_1g_2e_3g_4\rangle,\\
&U_4|\psi_0\rangle=|\psi_4\rangle=\frac{1}{\sqrt{2}}(|e_1g_2g_3e_4\rangle+\mathrm{i}|g_1e_2e_3g_4\rangle, U_5|\psi_0\rangle=|\psi_5\rangle=\frac{1}{\sqrt{2}}(|e_1g_2e_3e_4\rangle-\mathrm{i}|g_1e_2g_3g_4\rangle,\\
&U_6|\psi_0\rangle=|\psi_6\rangle=\frac{1}{\sqrt{2}}(|e_1e_2e_3e_4\rangle+\mathrm{i}|g_1g_2g_3g_4\rangle, U_7|\psi_0\rangle=|\psi_7\rangle=\frac{1}{\sqrt{2}}(|e_1e_2g_3e_4\rangle-\mathrm{i}|g_1g_2e_3g_4\rangle,
\end{aligned}$$

$$U_8|\psi_0\rangle = |\psi_8\rangle = \frac{1}{\sqrt{2}}(|g_1g_2g_3e_4\rangle - \mathrm{i}|e_1e_2e_3g_4\rangle, U_9|\psi_0\rangle = |\psi_9\rangle = \frac{1}{\sqrt{2}}(|g_1g_2e_3e_4\rangle + \mathrm{i}|e_1e_2g_3g_4\rangle,$$
$$U_{10}|\psi_0\rangle = |\psi_{10}\rangle = \frac{1}{\sqrt{2}}(|g_1e_2e_3e_4\rangle - \mathrm{i}|e_1g_2g_3g_4\rangle, U_{11}|\psi_0\rangle = |\psi_{11}\rangle = \frac{1}{\sqrt{2}}(|g_1e_2g_3e_4\rangle + \mathrm{i}|e_1g_2e_3g_4\rangle,$$
$$U_{12}|\psi_0\rangle = |\psi_{12}\rangle = \frac{1}{\sqrt{2}}(-|e_1g_2g_3e_4\rangle + \mathrm{i}|g_1e_2e_3g_4\rangle, U_{13}|\psi_0\rangle = |\psi_{13}\rangle = \frac{1}{\sqrt{2}}(-|e_1g_2e_3e_4\rangle - \mathrm{i}|g_1e_2g_3g_4\rangle,$$
$$U_{14}|\psi_0\rangle = |\psi_{14}\rangle = \frac{1}{\sqrt{2}}(-|e_1e_2e_3e_4\rangle + \mathrm{i}|g_1g_2g_3g_4\rangle, U_{15}|\psi_0\rangle = |\psi_{15}\rangle = \frac{1}{\sqrt{2}}(-|e_1e_2g_3e_4\rangle - \mathrm{i}|g_1g_2e_3g_4\rangle. \tag{14}$$

Now user 1, 2 and 3 send their atoms to user 4. In this case user 4 has 4 atoms 1, 2, 3, 4. Then user 4 let the four atoms simultaneously interact with another single-mode cavity and at the same time four atoms are driven by a classical field. The system evolution is described by Eq.(3). With the choice of $\lambda\tau = \pi/4, \Omega\tau = \pi(\tau$ is the interaction time), the above quantum state will be

$$|\psi_0\rangle \to \mathrm{i}|e_1e_2e_3g_4\rangle, \quad |\psi_1\rangle \to |g_1g_2e_3e_4\rangle,$$
$$|\psi_2\rangle \to \mathrm{i}|e_1g_2g_3g_4\rangle, \quad |\psi_3\rangle \to |g_1e_2g_3e_4\rangle,$$
$$|\psi_4\rangle \to \mathrm{i}|g_1e_2e_3g_4\rangle, \quad |\psi_5\rangle \to |e_1g_2e_3e_4\rangle,$$
$$|\psi_6\rangle \to \mathrm{i}|g_1g_2g_3g_4\rangle, \quad |\psi_7\rangle \to |e_1e_2g_3e_4\rangle,$$
$$|\psi_8\rangle \to |g_1g_2g_3e_4\rangle, \quad |\psi_9\rangle \to \mathrm{i}|e_1e_2g_3g_4\rangle,$$
$$|\psi_{10}\rangle \to |g_1e_2e_3e_4\rangle, \quad |\psi_{11}\rangle \to \mathrm{i}|e_1g_2e_3g_4\rangle,$$
$$|\psi_{12}\rangle \to -|e_1g_2g_3e_4\rangle, \quad |\psi_{13}\rangle \to -\mathrm{i}|g_1e_2g_3g_4\rangle,$$
$$|\psi_{14}\rangle \to -|e_1e_2e_3e_4\rangle, \quad |\psi_{15}\rangle \to -\mathrm{i}|g_1g_2e_3g_4\rangle. \tag{15}$$

Hence, the GHZ-state measurement can be achieved by detecting atoms 1, 2, 3, 4 separately. With the measurements on user 4's four atoms, user 4 can identify 16 operations on state $|\psi_0\rangle$, that is, what the messages are that users 1, 2, 3 have encoded in the quantum state.

Case II where N+1 is odd. The quantum dense coding procedure is the same as in case I except for the choice of $\lambda t = \pi/4$ and $\Omega t = 2n\pi + 3\pi/4$ ($\lambda\tau = \pi/4, \Omega\tau = 2n\pi + 3\pi/4$). Now we take 3-party dense coding for example. Consider the initial state of three atoms 1, 2 and 3 to be $|g_1g_2e_3\rangle$. With the choice of $\lambda t = \pi/4$ and $\Omega t = 3\pi/4$, the system evolves to the following state from the evolution operator in Eq.(3):

$$|\psi_0'\rangle = \frac{1}{\sqrt{2}}(|g_1g_2e_3\rangle + \mathrm{i}|e_1e_2g_3\rangle). \tag{16}$$

Then user 1 and user 2 perform the following unitary operation on their atoms:

$$U_0' = \sigma_z \otimes \sigma_z, \quad U_1' = I \otimes \sigma_z,$$
$$U_2' = \mathrm{i}\sigma_y \otimes \sigma_z, \quad U_3' = \sigma_x \otimes \sigma_z,$$
$$U_4' = I \otimes \sigma_x, \quad U_5' = \sigma_z \otimes \sigma_x,$$
$$U_6' = \sigma_x \otimes \sigma_x, \quad U_7' = \mathrm{i}\sigma_y \otimes \sigma_x. \tag{17}$$

The eight operations will transform $|\psi_0'\rangle$ to different GHZ-states,

$$U_0'|\psi_0'\rangle = |\psi_0'\rangle = \frac{1}{\sqrt{2}}(|g_1g_2e_3\rangle + \mathrm{i}|e_1e_2g_3\rangle),$$
$$U_1'|\psi_0'\rangle = |\psi_1'\rangle = \frac{1}{\sqrt{2}}(|g_1g_2e_3\rangle - \mathrm{i}|e_1e_2g_3\rangle),$$
$$U_2'|\psi_0'\rangle = |\psi_2'\rangle = \frac{1}{\sqrt{2}}(-|e_1g_2e_3\rangle - \mathrm{i}|g_1e_2g_3\rangle),$$
$$U_3'|\psi_0'\rangle = |\psi_3'\rangle = \frac{1}{\sqrt{2}}(|e_1g_2e_3\rangle - \mathrm{i}|g_1e_2g_3\rangle),$$
$$U_4'|\psi_0'\rangle = |\psi_4'\rangle = \frac{1}{\sqrt{2}}(|g_1e_2e_3\rangle + \mathrm{i}|e_1g_2g_3\rangle),$$
$$U_5'|\psi_0'\rangle = |\psi_5'\rangle = \frac{1}{\sqrt{2}}(|g_1e_2e_3\rangle - \mathrm{i}|e_1g_2g_3\rangle),$$
$$U_6'|\psi_0'\rangle = |\psi_6'\rangle = \frac{1}{\sqrt{2}}(|e_1e_2e_3\rangle + \mathrm{i}|g_1g_2g_3\rangle),$$
$$U_7'|\psi_0'\rangle = |\psi_7'\rangle = \frac{1}{\sqrt{2}}(-|e_1e_2e_3\rangle + \mathrm{i}|g_1g_2g_3\rangle). \tag{18}$$

Then user 1 and user 2 send their atoms to user 3. In this case, user 3 let the three atoms interact with another single-mode cavity, at the same time the atoms are driven by a classical field. The system evolution is described by Eq.(3). With the same choice of $\lambda\tau = \pi/4$ and $\Omega\tau = 3\pi/4$ (τ is the interaction time), the eight states evolve to orthogonal product states

$$|\psi_0'\rangle \to \mathrm{i}|e_1e_2g_3\rangle, \quad |\psi_1'\rangle \to |g_1g_2g_3\rangle,$$
$$|\psi_2'\rangle \to -\mathrm{i}|g_1e_2g_3\rangle, \quad |\psi_3'\rangle \to |e_1g_2e_3\rangle,$$
$$|\psi_4'\rangle \to \mathrm{i}|e_1g_2g_3\rangle, \quad |\psi_5'\rangle \to |g_1e_2e_3\rangle,$$
$$|\psi_6'\rangle \to \mathrm{i}|g_1g_2g_3\rangle, \quad |\psi_7'\rangle \to -|e_1e_2e_3\rangle. \tag{19}$$

Hence, the GHZ-state measurement can be achieved by detecting atoms 1, 2 and 3 separately. With the

measurement on user 3's three atoms, user 3 can read out the messages user 1 and user 2 have encoded. So he receives 3 bits of classical information from user 1 and 2. Thus the dense coding is achieved.

4. Experimental results and conclusion

It is noted that in the case when $N + 1 = 2$ we obtain the result of two-particle quantum dense coding in Ref.[10]. Based on cavity QED techniques presently the proposed scheme has the same experimental results as those in Ref.[10], namely, for the Rydberg atoms with principal quantum numbers 49, 50, 51, the radiative time is about $T_r = 3 \times 10^{-2}$ s, and the coupling constant is $g = 2\pi \times 24$kHz.[21,22] The required atom-cavity-field interaction time is on the order of $T \approx 10^{-4}$s. Then the time needed to complete the whole procedure is much shorter than T_r. During the preparation of the entangled state and the GHZ-state measurement, our scheme only involves atom-field interaction with a large detuning and does not require the transfer of quantum information between the atoms and the cavity. In addition, with the help of a strong classical driving field the photon-number-dependent parts in the evolution operator are cancelled. Thus the protocol is insensitive to both cavity decay and thermal field, which is important from the experimental point of view.

In conclusion, we generalize the scheme of biparty dense coding[10] to multiparty case by using the interaction of $N + 1$ two-level atoms with a single-mode nonresonant cavity with the assistance of a strong classical driving field. Our protocol provides a way to achieve the operations of dense coding: the generating of entangled states and measuring of GHZ-state. GHZ states can be exactly identified by detecting atoms separately. Thus, the complexity of GHZ-state measurement is reduced. We hope that our protocol can be useful for further study of quantum dense coding and other quantum information processing in multiparty system.

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