Annals of Physics 360 (2015) 462–476

Contents lists available at ScienceDirect

Annals of Physics

journal homepage: www.elsevier.com/locate/aop

Long distance atomic teleportation with as good success as desired

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ARTICLE INFO

Article history:
Received 1 February 2015
Accepted 18 May 2015
Available online 27 May 2015

Keywords:
Quantum teleportation
Coherent states
Fidelity
Bell state measurement

ABSTRACT

Long distance atomic teleportation (LDAT) is of prime importance in long distance quantum communication. Scheme proposed by Bose et al. (1999) in principle enables us to have LDAT using cavity decay. However it gives message state dependent fidelity and success rate. Here, using interaction of entangled coherent states with atom–cavity systems and a two-step measurement, we show how, LDAT can be achieved with unit fidelity and as good success as desired under ideal conditions. The scheme is unique in that, the first measurement predicts success or failure. If success is predicted then second measurement gives perfect teleportation. If failure is predicted the message-qubit remains conserved therefore a second attempt may be started. We found that even in presence of decoherence due to dissipation of energy our scheme gives message state independent success rate and almost perfect teleportation in single attempt with mean fidelity of teleportation equal to 0.9 at long distances. However if first attempt fails, unlike ideal case where message-qubit remains conserved with unit fidelity, in presence of decoherence the message-qubit remains conserved to some degree, therefore mean fidelity of teleportation can be increased beyond 0.9 by repeating the process.

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http://dx.doi.org/10.1016/j.aop.2015.05.021
0003-4916/

1. Introduction

Any attempt at measuring quantum information disturbs it irreversibly and yields incomplete information. This makes it impossible to clone an unknown quantum state and to transmit it through a classical channel. Quantum teleportation [1] is to circumvent this impossibility so as to allow the faithful transmission of quantum information encoded in an unknown state vector of a local quantum system to another system across space using long range EPR correlations [2] and a two-bit classical channel. Bowmeester et al. [3] have experimentally demonstrated the teleportation of a single photon polarized-state using standard bi-photonic Bell state (SBBS) with success rate equal to 0.5. The low success rate is due to the fact that complete Bell state measurement (BSM) of SBBS cannot be performed without nonlinear interaction [4]. Kim et al. [5], reported unit success rate using sum frequency generation for BSM. These experiments [3,5] with SBBS proved the principle of quantum teleportation, but are commercially inapplicable due to low efficiency in production and detection of single photon, requirement of complex nonlinear interactions and sudden loss of entanglement due to photon absorption.

In recent past entangled coherent states (ECS) [6–8]

$$|\psi_{\pm}\rangle_{a,b} = N_{\pm}\left[|\alpha, \alpha\rangle \pm |-\alpha, -\alpha\rangle\right]_{a,b}, \tag{1}$$

$$|\varphi_{\pm}\rangle_{a,b} = N_{\pm}\left[|\alpha, -\alpha\rangle \pm |-\alpha, \alpha\rangle\right]_{a,b} \tag{2}$$

where

$$N_{\pm} = \left[2(1 \pm x^4)\right]^{-1/2}, \quad x = \exp\left(-|\alpha|^2\right), \tag{3}$$

have attracted much attention. ECS are more robust against decoherence due to photon absorption than the SBBS [6]. Authors in Refs. [9,10] have shown that by mixing two entangled modes of ECS over a 50:50 beam splitter followed by photon counting in output modes, one can precisely discriminate four ECS for large mean photon numbers of the order of $|\alpha|^2$. Therefore, ECS with large $|\alpha|^2$ circumvents the necessity of non-linear interaction for BSM. These advantages of ECS led large number of proposals for teleportation of single-qubit [11–13] and two-qubit [14–16] superposed coherent state (SCS) using ECS as quantum channel. Jeong et al. [17] studied the universal quantum computation using ECS. Recently, Nielsen et al. [18] experimentally demonstrated the coherent-state quantum computing where ECS is used as entanglement resource for quantum teleportation of coherent state with an amplitude gain.

From practical point of view, single-photon and SCS are not ideal for long term storage of quantum information as they are very difficult to keep in a certain place. However, since atoms can be trapped for 2–3 s [19–21] therefore, atoms are ideal for quantum information storage. For these reasons, many schemes [22–25] for atomic teleportation using atom–cavity interactions and atoms as flying qubit have been proposed. Since atoms move slowly and interact strongly with their environment, these schemes are unable to perform long distance atomic teleportation (LDAT). LDAT is of particular importance due to its applicability in secure quantum communication and in linking two quantum processors working distant apart. Scheme proposed by Bose et al. [26] in principle enables us to have LDAT. This scheme involves mapping of atomic state to a cavity state with Alice, followed by the detection of photons leaking out from Alice's cavity and Bob's cavity (initially in maximally entangled atom–cavity state) by mixing over a beam splitter. The main shortcoming of this scheme is that the teleportation fidelity and success rate depends on the state to be teleported. Under reasonable cavity parameters and cavity decay time $t_D = 50\ \mu$s, success rate is near 0.5 with average teleportation fidelity greater than 0.9. Further Chimczak et al. [27], pointed out the inefficiency of scheme [26] due to large damping values of currently available cavities that reduces the fidelity of state mapping from atom to cavity and discussed a modification using non-maximally entangled atom–cavity state with amplitudes chosen in such a way that compensates the damping factors due to state mapping. This resolves the effect of damping at the cost of further decrease in success rate. Moreover, both schemes [26,27] are expected to suffer decoherence due to photon absorption while propagating toward beam splitter and on failure, both schemes completely destroy the message state. This requires many stages of atom–cavity interaction and single photon detection ability. For all these