Annals of Physics 350 (2014) 137–145

Contents lists available at ScienceDirect

Annals of Physics

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

Enhancing teleportation fidelity by means of weak measurements or reversal

Liang Qiu [a,*], Gang Tang [a], Xianqing Yang [a], Anmin Wang [b]

[a] College of Sciences, China University of Mining and Technology, Xuzhou 221116, China

[b] Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China

HIGHLIGHTS

- The method's probabilistic nature should be responsible for the improvement.
- Quantum or classical correlation cannot explain the improvement.
- The receiver cannot apply weak measurements.
- The sender's quantum measurement reversal is only useful for $|\Psi^{\pm}\rangle$.

ARTICLE INFO

Article history:
Received 10 October 2013
Accepted 5 July 2014
Available online 12 July 2014

Keywords:
Teleportation
Amplitude damping channel
Weak measurement
Quantum measurement reversal

ABSTRACT

The enhancement of teleportation fidelity by weak measurement or quantum measurement reversal is investigated. One qubit of a maximally entangled state undergoes the amplitude damping, and the subsequent application of weak measurement or quantum measurement reversal could improve the teleportation fidelity beyond the classical region. The improvement could not be attributed to the increasing of entanglement, quantum discord, classical correlation or total correlation. We declare that it should be owed to the probabilistic nature of the method.

1. Introduction

Quantum teleportation [1] is understood to send quantum information from one object to another object using entanglement, where the spatially separated sender (Alice) and receiver (Bob) are only

* Corresponding author.
E-mail addresses: lqiu@cumt.edu.cn, lqiu1981@mail.ustc.edu.cn (L. Qiu).

http://dx.doi.org/10.1016/j.aop.2014.07.012
0003-4916/

allowed to perform local quantum operations and communicate among themselves via a classical channel [2]. In the primitive teleportation scheme, a class of maximally entangled states, which are given by $|\Phi^{\pm}\rangle = (|00\rangle \pm |11\rangle)/\sqrt{2}$, $|\Psi^{\pm}\rangle = (|01\rangle \pm |10\rangle)/\sqrt{2}$, are shared between the sender and the receiver. The four states are called Bell states and are locally unitary equivalent because they are mapped onto each other by local Pauli rotations. *Teleportation has attracted considerable attention theoretically* [3–11] *and experimentally* [12–16].

In reality, however, the maximally entangled states become mixed due to the interactions between the transmitted qubit and the environment during sharing of quantum entanglement or imperfections of preparation. The noisy state is of few significant for information processing. Moreover, if the noisy state is mixed too much, it will not provide any better transmission fidelity than that of an ordinary classical communication channel [17]. In order to answer the question that whether the states can offer nonclassical fidelity within the original teleportation scheme supplemented by local unitary rotations, fully entangled fraction for a bipartite entangled state ρ in $C^2 \otimes C^2$ is defined as

$$f(\rho) = \max_{|\psi\rangle} \langle\psi|\rho|\psi\rangle. \tag{1}$$

Here, the maximum is taken over all maximally entangled states $|\psi\rangle$ [18]. In the standard teleportation scheme, the fully entangled fraction f relates to the teleportation fidelity F by $F = (2f + 1)/3$. $f > 1/2$ should be satisfied in order to make sure the state ρ to be useful for quantum teleportation, as one can achieve the fidelity $2/3$ on average classically.

Recently, it is pointed out that weak measurements, together with quantum measurement reversals, protect quantum states of single quantum systems [19–21], and it is extended to protect entanglement of two-qubit systems [22–25]. Weak measurement does not totally collapse the measured system to eigenstate randomly so that it is reversible, thereby contrasting with an ordinary projective one [26]. Thus, it would be possible to recover the initial state with some operations [27,28]. Probabilistic reversal with a weak measurement has already been demonstrated experimentally on a superconducting phase qubit [29], as well as on a photonic qubit [23,30]. *Very recently, weak measurement and a subsequent reverse operation are found to be able to improve the fidelity of teleportation when one or both qubits of a maximally entangled state shared between the sender and the receiver undergo amplitude damping* [31]. *The protocol is shown to work even for the Werner state.*

In this paper, we uncover some curious features that arise as one of the qubits in a maximally entangled state interacts with the environment via an amplitude damping channel. Specially, suppose we have a bipartite maximally entangled state ρ^{AB} (one of the four Bell states), and the qubit B undergoes local interactions with its environment via the amplitude damping channel. Different from Ref. [31], we investigate the following two cases. Firstly, after the receiver receives the qubit B, he applies the quantum measurement reversal or weak measurement on his qubit. Secondly, when the sender gets the information that Bob has received the qubit B, she employs the quantum measurement reversal or weak measurement on her own qubit A. The effects of Alice's (or Bob's) operations on the teleportation fidelity will be investigated.

The paper is arranged as follows. We review the result while sharing a Bell state across amplitude damping channel and the definitions of weak measurement and quantum measurement reversal in Section 2. Subsequently, in Section 3, improving the teleportation fidelity via weak measurement or quantum measurement reversal is discussed. Finally, we conclude in Section 4.

2. Sharing a Bell state across amplitude damping channel

The amplitude damping channel is employed to describe the interaction between a two-level atom and the electromagnetic field (environment). The detail could be found in Ref. [32]. If the environment is a vacuum with zero temperature, amplitude damping corresponds to the following map

$$\begin{aligned} &|0\rangle_S|0\rangle_E \rightarrow |0\rangle_S|0\rangle_E, \\ &|1\rangle_S|0\rangle_E \rightarrow \sqrt{1-p}|1\rangle_S|0\rangle_E + \sqrt{p}|0\rangle_S|1\rangle_E, \end{aligned} \tag{2}$$

where $p \in [0, 1]$. It indicates that if an atom is in an excited state $|1\rangle_S$, it makes a transition to the ground state $|0\rangle_S$ with the emission of a photon with probability p, while the environment makes a