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Inducing multipartite entanglement revival in dissipative environment by means of prior quantum uncollapsing measurements

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HIGHLIGHTS

- We propose a way for inducing multipartite entanglement revival from decoherence.
- The effect is more pronounced for the given system with less initial entanglement.
- Our scheme also works for the N-qubit GHZ-class state.

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ABSTRACT

A scheme for inducing multipartite entanglement revival in the dissipative environment is proposed, which is implemented by performing a prior quantum uncollapsing (weak measurements or measurement reversals) procedure on partial qubits of the system simultaneously. This procedure preferentially equips our initial states, and make them hold more powerful ability to actively battle against degradation of entanglement, even postpone entanglement sudden death (ESD). Notably, the effect is more pronounced for the multipartite system with less initial entanglement. In addition, we found that our scheme also works for the N-qubit GHZ-class state.

1. Introduction

Nowadays, it is generally believed that quantum entanglement is one of the most significant concepts in quantum information science, since it provides some novel ideas in developing quantum communication and quantum computation. However, in realistic quantum information processing, entanglement is inevitably suffered from quantum decoherence. That is, the interaction between the system and its external environment will lead to the degradation of quantum coherence and even generates entanglement sudden death (ESD) [1–5] in certain cases. So far, more and more people pay their attention to seek ways to cope with decoherence [6–13], and several effective schemes have been proposed, such as entanglement distillation [6,7], decoherence-free subspace [9], and quantum Zeno effect [10,11]. Very recently, another method named weak measurement, which is generalizations of Von Neumann measures and relevant to the positive-operator valued measure (POVM) [14], has been introduced to suppress decoherence. It is verified that weak measurement can be reversed and effectively combat amplitude-damping decoherence for two-qubit system [1,15] experimentally. Consequently, a lot

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of extended investigations [14,16–22] for protecting entanglement from decoherence by means of this method have been presented. Nevertheless, we notice that all the investigations discussed this topic are associated with the two-qubit systems. Meanwhile, since the multi-qubit entanglement is a hard quantity to evaluate, very little research has pursued how to suppress decoherence and control entanglement for a larger system [23].

On the other hand, it was shown that the degradation of entanglement becomes more sharp with the increasing number of qubits entering the dissipative environment [24]. There is no doubt that it is a significant task to explore effective methods for protecting entanglement and suppressing decoherence for multipartite system. Enlightened by the above-mentioned schemes, in this paper, we focus on investigating the dynamical evolution of multi-qubit state in dissipative environment and seeking the way to protect entanglement. Since the entanglement cannot be resurged by weak measurements, we devise a method that utilizes prior measurements to induce multipartite entanglement revival in dissipative environment.

The structure of the paper is as follows. In Section 2, we review the physical model of the multipartite system locally interacting with its dissipative environment. In Section 3, we demonstrate our scheme to induce multipartite entanglement revival in detail. Finally, discussion and a brief summary are shown in Section 4.

2. Physical model of multipartite system locally interacting with its dissipative environment

In this section, we investigate the physical model of the multipartite system locally interacting with the Markovian dissipative environment. Here, dissipative effects are depicted by means of the coupling of the system to a thermal bath at zero temperature, and can represent, for example, the spontaneous decay of a two level atom induced by its interaction with the vacuum modes of the ambient electromagnetic field [24]. Then, evolution of the reduced density matrix for the central system can be given by the solution of the following Markovian master equation with Lindblad structure [25].

$$\frac{\mathrm{d}}{\mathrm{d}t}\rho(t) = -\mathrm{i}[H_s, \rho(t)] + \sum_m \frac{\gamma_m}{2}(2L_m\rho(t)L_m^\dagger - \{L_m^\dagger L_m, \rho(t)\}) \quad (\hbar = 1), \tag{1}$$

where H_s is the system Hamiltonian, γ_m represents the coupling strengths between the qubits and their respective environments, the decoherence dynamic is described by Lindblad operators $L_m = \sigma_m^- = \frac{\sigma_x - \mathrm{i}\sigma_y}{2}$ acts on the mth qubit, σ_x and $\sigma_y$are the usual Pauli spin operators and the brace { } denotes the anticommutator. For simplicity, we assume that the strengths of the coupling between each of the qubits and its environment are equal, and the Hamiltonian of the A–B–C system is zero, namely $H_s = 0$, which means the qubits are separated by spatial distances large enough and thus there are no direct interactions between them.

To simplify, we first consider the GHZ-class state of the following form

$$|\psi\rangle_{ABC} = \alpha\,|000\rangle_{ABC} + \beta\,|111\rangle_{ABC}\,, \qquad |\alpha|^2 + |\beta|^2 = 1. \tag{2}$$

It is convenient to employ the form of density matrix $\rho = |\psi\rangle_{ABC}\langle\psi|$ and its matrix elements ρ_{uv} $(u = 1, 2, \ldots, 8, v = 1, 2, \ldots, 8)$ for calculating the time evolution of GHZ state when they are subjected to the Markovian environment. Under the basis $\{|000\rangle, |001\rangle, |010\rangle, |011\rangle, |100\rangle, |101\rangle, |110\rangle, |111\rangle\}$, the initial matrix elements of the GHZ state, except for $\rho_{11}(0) = |\alpha|^2$, $\rho_{18}(0) = \alpha\beta^*$, $\rho_{81}(0) = \beta\alpha^*$, $\rho_{88}(0) = |\beta|^2$, and the rest matrix elements are$\rho_{uv} = 0$. By solving the corresponding master equation (1), we can acquire the nonzero elements of the evolved density matrix $\rho_{uv}(t)$ as

$$\rho_{uv}(t) = \begin{bmatrix} \rho_{11} & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{18} \\ 0 & \rho_{22} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_{33} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_{44} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_{55} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \rho_{66} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \rho_{77} & 0 \\ \rho_{81} & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{88} \end{bmatrix}, \tag{3}$$

where $\rho_{11} = |\alpha|^2\,\mathrm{e}^{-3\gamma t}$, $\rho_{18} = \rho_{81}^* = \mathrm{e}^{-\frac{3\gamma t}{2}}\alpha\beta^*$, $\rho_{22} = \rho_{33} = \rho_{55} = |\alpha|^2\,\mathrm{e}^{-3\gamma t}(-1 + \mathrm{e}^{\gamma t})$, $\rho_{44} = \rho_{66} = \rho_{77} = |\alpha|^2\,\mathrm{e}^{-3\gamma t}(-1 + \mathrm{e}^{\gamma t})^2$ and $\rho_{88} = \mathrm{e}^{-3\gamma t}(-|\alpha|^2 + 3e^{\gamma t}|\alpha|^2 - 3e^{2\gamma t}|\alpha|^2 + \mathrm{e}^{3\gamma t})$.

The effect of decoherence on the initial state can be studied by evaluating concurrence which quantifies the amount of entanglement. For N-partite pure states $|\Psi\rangle \in H_1 \otimes H_2 \otimes H_3 \cdots \otimes H_N$, where H represents the Hilbert space, the multipartite concurrence can be defined as

$$C_{|\Psi\rangle} = \min_{\tau_i \in \tau} \sqrt{2}\sqrt{1 - Tr(\rho^2_{A_{\tau_i}})}, \tag{4}$$

where $\tau = \{\tau_i\}$ represents the set of all possible bipartitions $\{A_i|B_i\}$ of $\{1, 2, 3, \ldots, \mathrm{N}\}$. Particularly, according to Ref. [26], as an indicator of entanglement for N-qubit X states