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Quantum Fisher information of an open and noisy system in the steady state

Azmi Ali Altintas

Faculty of Engineering and Architecture, Okan University, Istanbul, Turkey

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ABSTRACT

We study the quantum Fisher information (QFI) per particle of an open (particles can enter and leave the system) and dissipative (far from thermodynamical equilibrium) steady state system of two qubits in a noise which is decoherence. We show the behavior of QFI per particle of the system due to changes of reset and decoherence parameters r and γ respectively. The parameter r is the strength of the reset mechanism, γ is the strength of decoherence and in our case it is dephasing channel. The parameters γ and r are real numbers. We observe that the reset parameter must be bigger than decoherence parameter. We have found that by choosing coupling parameter g as 5γ the QFI per particle is 1.00226 which is greater than shot noise limit at $\gamma = 0.5$ and $r = 14$. Also the concurrence and negativity of the such state have been calculated and they are found as 0.0992486 and 0.0496243 respectively. We have shown that when the concurrence and negativity of some specific states different than zero, which means the state is entangled, the QFI of the system is greater than 1. The QFI per particle, concurrence and negativity shows that the chosen case is weakly entangled. We discovered that the optimal direction depends on the parameters r and γ and a change in the direction affects the behavior of the QFI of the system.

E-mail address: altintas.azmiali@gmail.com.

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1. Introduction

Quantum Fisher information (QFI) which characterizes the sensitivity of a quantum system with respect to the changes of a parameter of the system has been shown to be a multipartite entanglement criteria [1,2]: If the mean quantum Fisher information per particle of a state exceeds the so called *shot-noise limit* i.e. the ultimate limit that separable states can provide, then the state is multipartite entangled. *Shot-noise limit* is $\Delta\theta \equiv \frac{1}{\sqrt{N}}$, where N is the number of particles [3]. The converse is not generally true that not all pure multipartite entangled states achieve this limit, i.e. they are not *useful for sub-shot-noise interferometry* even if optimized by local operations. The only exception is for $N = 2$ case, at that case any entangled state can be made useful by local operations [4]. It is also shown that GHZ states provide the largest sensitivity, achieving the fundamental, so called Heisenberg limit [5]. Mean QFI determines the phase sensitivity of state with respect to SU(2) rotations. Recently the quantum Fisher information has been further studied both theoretically and experimentally [6–27]. Quantum Fisher information is mainly related with quantum estimation theory and there are some recent works about quantum estimation in open systems [28,29].

In nature it is hard to find controlled and closed systems. Usually the natural systems are open and noisy. If a quantum system interacts with environment it is thought as the quantum system is in a noisy channel. It is known that the entanglement of the quantum system decreases when the system is in a noisy channel. However for an open quantum system the decrease in entanglement can be balanced by a reset mechanism. With the help of reset mechanism an entangled steady state can be established. The reset mechanism replaces randomly particles of the quantum system with particles from the environment in some standard, sufficiently pure, single-particle state [30]. If the reset mechanism is taken alone, it cannot produce entanglement to the system. To create entanglement, the fresh particles must interact with the system. Since there is particle transfer from environment, the system must be open. Hartmann et al. shown that for both gas type and strongly coupled quantum systems the effect of decoherence can be vanished with the help of reset mechanism [31].

In this work, we study the quantum Fisher information per particle of open and dissipative noisy system of two qubits with reset mechanism. Because of its simplicity dephasing channel is used as decoherence channel in this study. It should also be noted that the quantum system is in a steady state. We examine the effect of reset mechanism if the strength of decoherence γ is taken to be constant. We observe that for the separability of the system, the strength of reset "r" must be well chosen to balance the effect of decoherence. Then by removing the restriction on γ we have looked for the quantum Fisher information of the quantum system and it is observed that the system remains separable by proper combinations of γ and r.

2. QFI of open noisy system in a steady state

The estimating parameters of a quantum state is one of the tasks of quantum information theory. Let ϕ be a parameter of a density matrix $\rho(\phi)$. The quantum Cramér–Rao bound is the bound for the variance of estimation of parameter ϕ.

$$\Delta\phi_{QCB} = \frac{1}{\sqrt{N_m F}}, \tag{1}$$

where N_m is the number of experiments and F is quantum Fisher Information. We consider that the parameter ϕ is obtained by SU(2) rotations.

$$\rho_\phi = U_\phi \rho U_\phi^\dagger, \tag{2}$$

where $U_\rho = e^{i\phi} J_{\vec{n}}$ and $J_{\vec{n}} = \sum_{\alpha=x,y,z} \frac{1}{2} n_\alpha \sigma_\alpha$, the angular momentum operator in $\vec{n}$ direction. σ_α are Pauli matrices.

In quantum metrology there are many methods to calculate the quantum Fisher information. One of the methods considered by Liu et al. [32] is a useful one for separable states. Another approach is about the general parametrization process $U = e^{-itH}$ for an initial pure state with time independent