Dynamics of quantum correlations in a qubit-qutrit spin system under random telegraph noise

Fadwa Benabdallah[1]. **Mohammed Daoud**[2,3]
[1] LPHE-Modeling and Simulation, Faculty of Sciences, Mohammed V University in Rabat, Rabat, Morocco
[2] Department of Physics, Faculty of Sciences, University Ibn Tofail, Kenitra, Morocco
[3] Abdus Salam International Centre for Theoretical Physics, Miramare, Trieste, Italy
E-mail : fadwa_benabdallah@um5.ac.ma

Introduction

- Quantum correlations lie in the foundations of quantum theory and have been of renewed interest during the last two decades as the field of quantum information science emerged and matured. Various quantifiers of quantum correlations have been further proposed to reveal the non-classical correlations that cannot be fully captured by quantum entanglement. Such us, the quantum discord (QD) allows one to reach all the non-classical correlations even beyond the entanglement, which may exist for mixed separable quantum states. There are some difficulties in operational quantum tasks involved with the QD that come from the problem of the QD through a minimization procedure [1]. For that reason, examining the QD has been bounded to only some particular cases such as interacted two-qubit systems. To keep away from these difficulties a geometric version of QD known as geometric quantum discord (GQD) is proved to be a good measure for quantum correlations [1]. Compared with quantum discord, the closed form of the GQD can be obtained for a large class of bipartite quantum states.
- It is well known that quantum systems inevitably interact with the environment when quantum information is processed in the real-world, which brings about the loss of initially presented quantum properties. This phenomenon can be characterized by decoherence, which can be illustrated by the example of faithfully transmitting an unknown quantum state through a noisy quantum channel. During the transmission, the carrier of the information interacts with the channel and gets correlated with other degrees of freedom. This gives rise to the phenomenon of so-called "decoherence" on the subspace of the information carrier.
- Recent studies on open quantum systems highlight the existence of two different classes of dynamical behaviors known as Markovian and non-Markovian environments. In the quantum domain, under certain assumptions, Markovian dynamics lead to a master equation in the Lindblad form. Nevertheless, for the case when the system-environment coupling is strong enough, this approximation method will fail. In this case, the non-markovian equations of the motion act as a crucial toolbox in order to investigate the time evolution of the density operator of a quantum system.
- For a deeper understanding of quantum phenomena, it is desirable to investigate the behaviors of the quantum properties under the action of decoherence. In this work, we showed that the geometric quantum discord and entanglement behave differently under the effect of the environment. In particular, for certain quantum states, the phenomenon of entanglement sudden death does not occur for quantum discord [1].
- Quantum systems with higher dimension may have advantages over ones with lower-dimensional quantum information processing, especially higher-dimensional quantum systems provide higher channel capacities, more secure cryptography as well as superior quantum gates as compared to qubits.

Method

- ➢ We propound a qubit-qutrit mixed spin-(1/2, 1) system that its subsystems A (with s = 1/2) and B (with S = 1) interact together via XXX Heisenberg exchange coupling under the effect of a transverse magnetic field. The Hamiltonian describes this initial thermal state system writes as

$$H_0 = J\left(S_A^x s_B^x + S_A^y s_B^y + S_A^z s_B^z\right) - \mu_B B\left(g_A S_A^z + g_B s_B^z\right)$$

where J is the coupling coefficient and B is the external magnetic field; S_A^α $(\alpha = x, y, z)$ denotes the spin-1 operator and s_B^α are the familiar Pauli matrices.

For a system in thermal equilibrium, the initial state of the system is given by the density operator

$$\rho_{AB}\,(0,T) = \exp(-\beta\, H)\,/Z$$

where $Z = Tr\,(\exp(-\beta\, H))$ is the partition function and $\beta = 1/k_B T$.

The time and temperature dependencies of the qubit-qutrit density matrix can be thus characterized in terms of the Kraus operators as

$$\rho_{AB}(t,T) = \sum_{i=1}^{2}\sum_{j=1}^{3}\left(K_i^A \otimes K_j^B\right)\rho_{AB}\,(0,T)\left(K_i^A \otimes K_j^B\right)^\dagger$$

where K_i^A and K_j^B Kraus operators representing the RTN dynamical map for the qubit and the qutrit, respectively. They satisfy the normalization condition $\sum_i K_i^\dagger K_i = I$.

- ➢ We study the dynamics of the entanglement by logarithmic negativity and geometric quantum discord in bipartite qubit-qutrit under random telegraph noise [1].

Conclusion

In summary, we have shown that at a special temperature interval the quantum entanglement based on the logarithmic negativity reveals entanglement sudden deaths together with revivals. The revival the phenomenon is due to the non-Markovianity resulting from the feedback effect of the environment. At high temperatures, the scenario of death and revival disappears. The geometric quantum discord evolves alternatively versus time elapsing with damped amplitudes until the system reaches steady state. It is demonstrated that the dynamics of entanglement negativity undergoes substantial changes by varying temperature, and it is much more fragile against the temperature rather than the geometric quantum discord.

Results

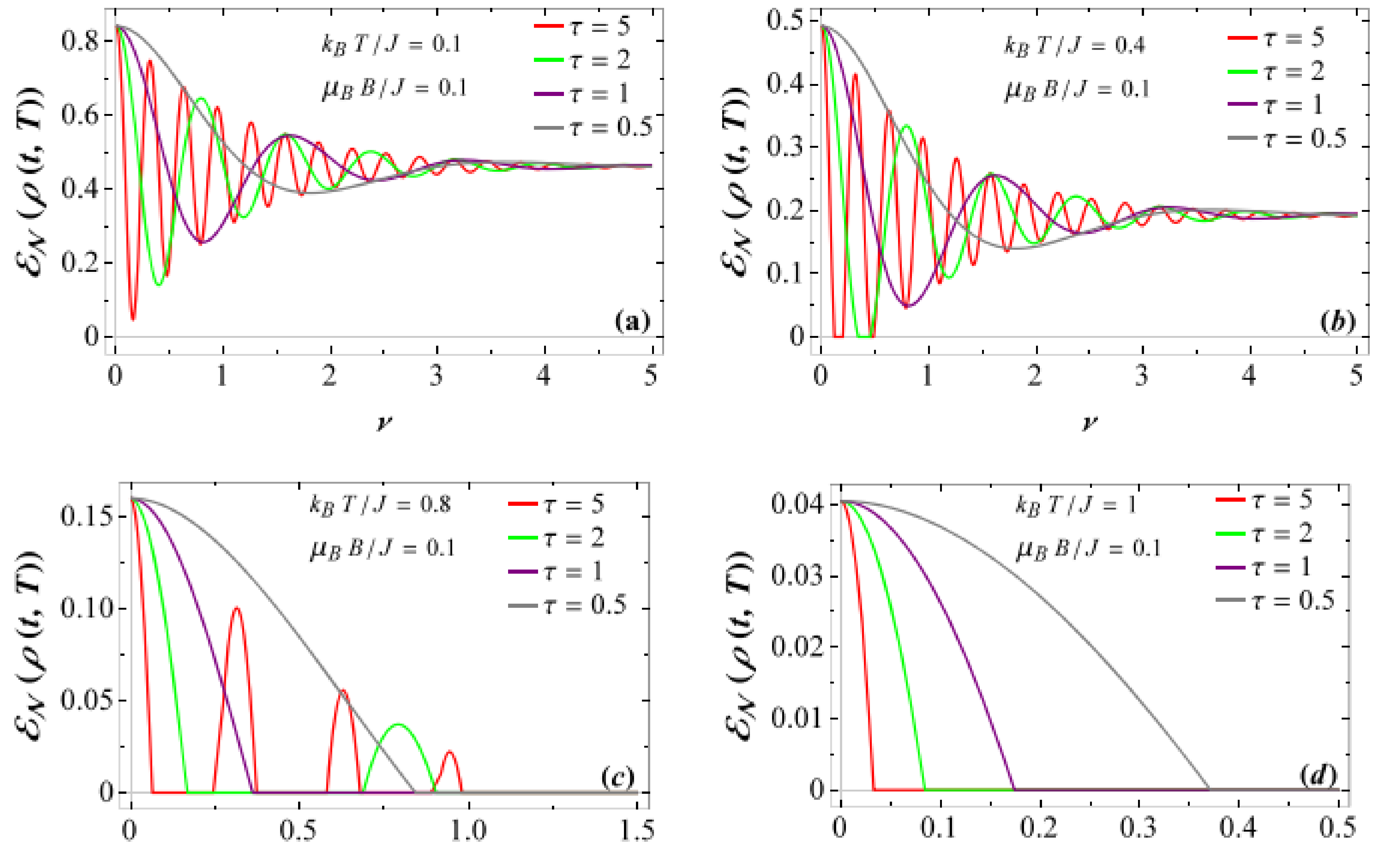

Figure1: Dynamics of logarithmic negativity (LN) versus dimensionless time $\vartheta = t/2\tau$ for $a = 1$ and a few fixed values of non-Markovianity parameter τ at four different temperatures.

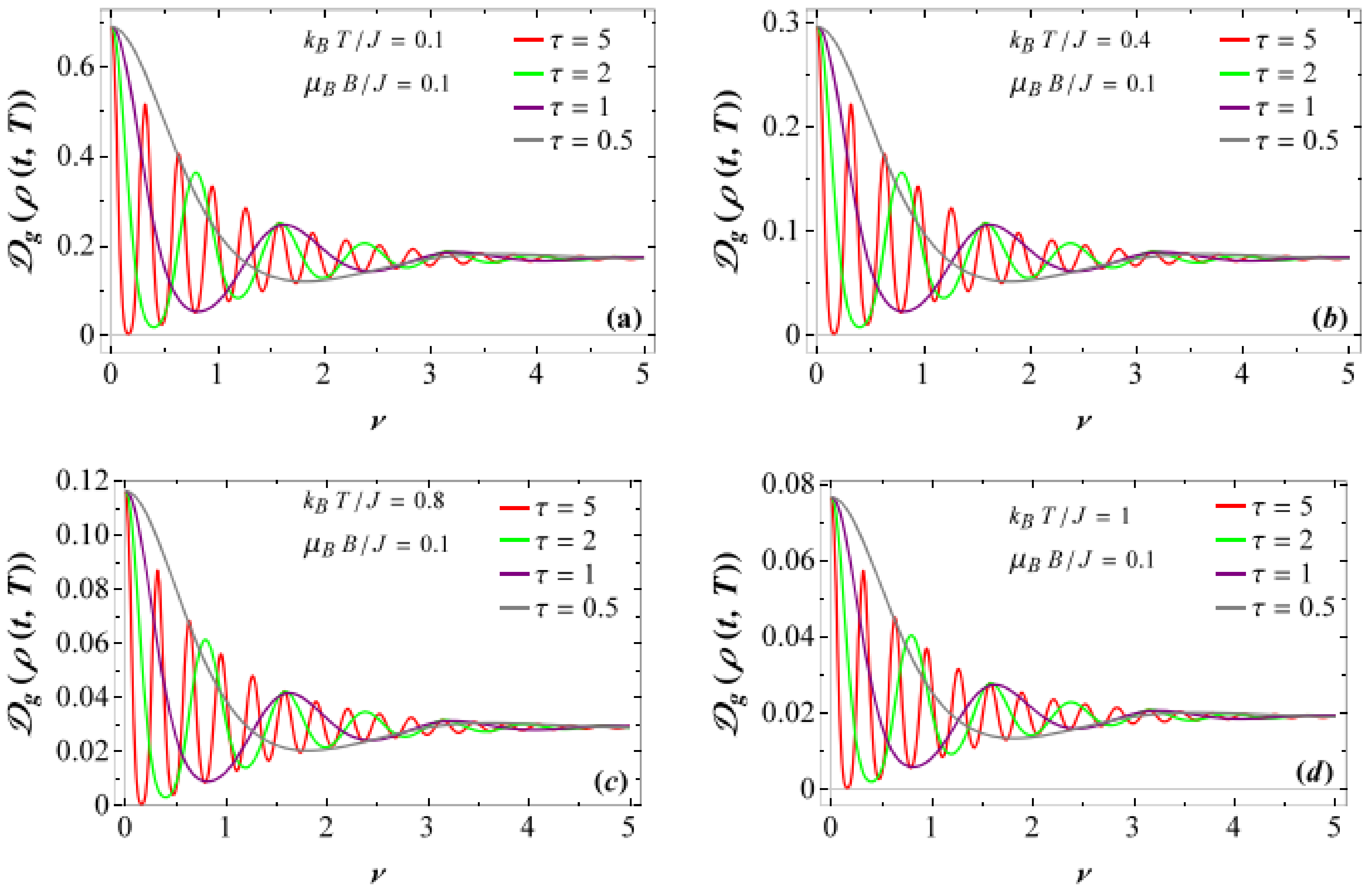

Figure2: Dynamics of GQD versus dimensionless time $\vartheta = t/2\tau$ for $a = 1$ and a few fixed values of non-Markovianity parameter τ at four different temperatures.

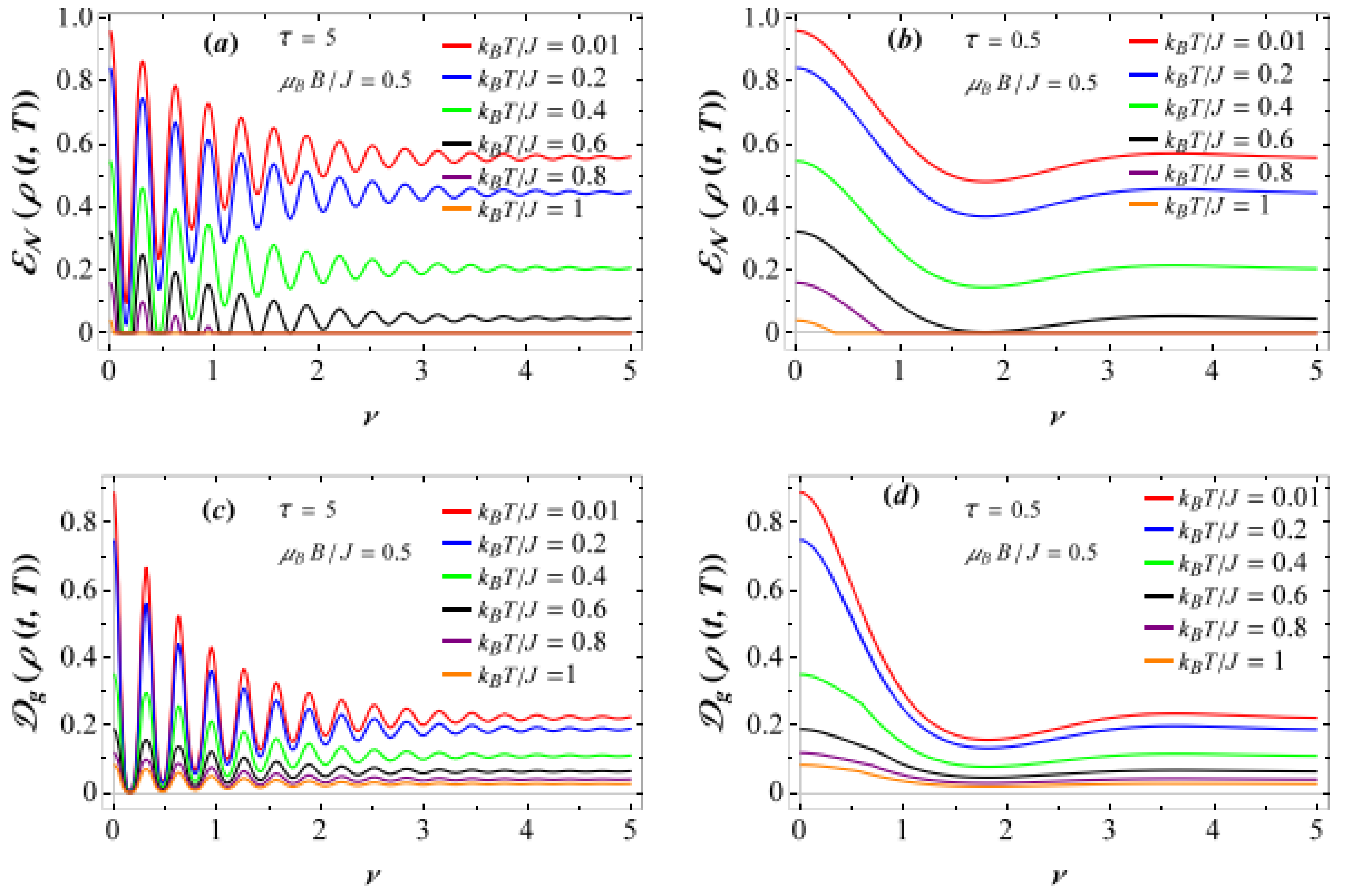

Figure 3. The LN versus time ν for $a = 1$ and several values of the temperature k_BT/J at fixed $\mu_BB/J = 0.5$, when (a) non-Markovian $\tau = 5$ and (b) Markovian $\tau = 0.5$ dephasing noise channels are considered. (c) and (d) depict the time evolution of the GQD where the same conditions to (a) and (b) have been supposed, respectively.

Refrences

[1] F. Benabdallah, H. Arian Zad, M. Daoud and N. Ananikian, Dynamics of quantum correlations in a qubit-qutrit spin system under random telegraph noise, Phys. Scr. 96 125116 (2021) .