On Non-Markovianity of Qubit Evolution under Action of Spin Environment

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In open system dynamics, a very important feature is the Markovianity or non-Markovianity of the environment. We consider a toy model here, with a qubit acting as a system and an environment consisting of a collection of non-interacting qubits. The interaction Hamiltionain is given by,

$$H_{se}(t) = \hbar\alpha\Big[|1\rangle_s\langle 0| \otimes \sum_{n=1}^{N} g_n^*(t)|0..0_n..0\rangle_e\langle 0..1_n..0|$$

$$+|0\rangle_s\langle 1| \otimes \sum_{n=1}^{N} g_n(t)|0..1_n..0\rangle_e\langle 0..0_n..0|\Big],$$

where coupling strength $g_n(t)$ is in general time-dependent and site-dependent, and α is a real parameter that scales with the interaction strength. So, although a toy model, it depicts a physical scenario where a two-level system exchanges an energy quantum with one of the environment qubits while the rest of the environment qubits are in their ground state. We take a superposition of this exchange interaction for each individual environment qubit, coupled with suitable strength $g_n(t)$. Following the idea of Rivas, Huelga, and Plenio,(2010) we device a non-Markovianity witness for the model. An additional ancilla qubit (which is not a part of the environment) is used for constructing the Witness. We examine the system-environment dynamics of our model for different types of coupling. We find that completely time-independent coupling and space-independent time-polynomial coupling gives rise to non-Markovianity. Also for space-independent exponentially decaying (in time) coupling, non-Markovianity is witnessed in certain regions of parameter values. We further analyse space and time-dependent coupling for some special cases and found extremal values of the coupling parameter that gives rise to non-Markovianity. These extremal values can be seen as transition values from fully non-Markovian to possibly Markovian dynamics. We also provide some support that would suggest this region of possible Markovianity is actually Markovian.

[1] D. Mandal, S. Chakraborty, A. Mallick and S. Ghosh. arXiv:1703.02749, (2017).