Cooling of Many-Body Systems via Selective Interactions

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Abstract

We propose a model describing N spin-1/2's coupled through N-order interaction terms, under local time-dependent fields. This model can be experimentally implemented with trapped ions and superconducting circuits current technologies. We succeed in exactly converting the quantum dynamics of this system into that of 2^{N-1} fictitious spin-1/2 dynamical problems. We show the possibility of generating GHZ states under specific time-dependent scenarios. Moreover, by appropriately engineering the time-dependence of the coupling parameters, one may choose a specific subspace in which the N-spin system dynamics takes place. This feature, called selective interaction, can generate a cooling effect of all N spins.

Trapped ions and superconducting circuits provide examples of quantum simulators of the dynamical behaviour of other quantum systems. A fascinating formal aspect of quantum simulation is the mathematical occurrence of local N-wise spin-1/2 coupling terms in the Hamiltonian. Here N-wise means that the interaction among the N spins may be represented as an N-degree homogeneous multilinear polynomial in the $3N$ dynamical variables of all the N spins. Such a kind of coupling is of course alien to physical context like nuclear, atomic, and molecular physics. However, the usefulness of such N-spin Hamiltonian models has been recently brought to light in the treatment and the study of fermion lattice models where many-body interactions are present [1]. Moreover, the physical relevance of these couplings can be found in the fct that it is possible to implement such many-body interactions through both trapped ions- [2] and superconducting transmon qubit-based techniques [3], exploiting collective entangling operations [4].

We have exactly solved a time-dependent model of N spin-1/2 systems comprising highly non-local interactions, namely [5]

$$H = \sum_{k=1}^{N} \hbar\omega_k(t)\hat{\sigma}_k^z + \gamma_x(t)\prod_{k=1}^{N}\hat{\sigma}_k^x + \gamma_y(t)\prod_{k=1}^{N}\hat{\sigma}_k^y + \gamma_z(t)\prod_{k=1}^{N}\hat{\sigma}_k^z.$$

$\hat{\sigma}^x$, $\hat{\sigma}^y$ and $\hat{\sigma}^z$ are the standard Pauli matrices. The coupling constants γ_x, γ_y and γ_z quantitatively characterize the three interaction terms and $\hbar\omega_k$ is the energy separation induced in the k-th spin by its relative field.

Firstly, we have shown that, thanks to non-local N-order interaction terms, it is possible to reverberate to all the spins in the system the dynamical effects generated in one of the N spins (ancilla qubit) by the application of a time-dependent field. This allows us to generate easily GHZ sates or a contemporary perfect inversion of all the spins. Secondly, we proposed a protocol through which we may generate a cooling effect of the whole spin system based on what we called selective interaction. The latter consists in the possibility to select a specific dynamically invariant subspace for a non-trivial dynamics of the N-spin system, by appropriately engineering the time-dependence of the coupling parameters. The key to get such physical results lies on the possibility to solve exactly the dynamics of the N-spin system by reducing the problem into a set of independent dynamical problems of single spin-1/2's.

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