Simultaneous quantum communication and multi-gate implementation across spin-chain channel https://doi.org/10.1103/PhysRevA.102.012418

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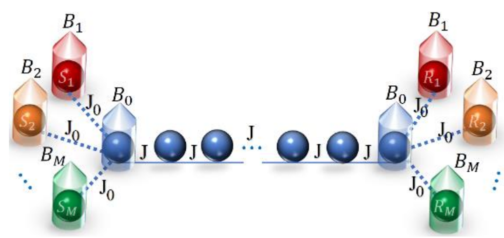
Abstract

The time evolution of spin chains has been extensively studied for both transferring quantum states and implementing quantum gates between distant registers of a quantum computer. Nonetheless, in most of the proposed protocols, operations can only be performed between a pair of channel users (qubits) at each time. This bottleneck significantly limits the rate of operation in quantum computers because communication and gate implementation between channel users can only be carried out sequentially. Here, we eliminate this critical obstacle by proposing an effective protocol that allows simulations two-way communication and multi-gate implementation between arbitrary number of users with no extra cost in the hardware level.

Keywords: Quantum state transfer, Entangling gates, Spin chains, Fidelity.

The natural dynamics of spin chains have been proposed [1] for short-range quantum communication required to integrate and scale-up quantum registers. Moreover, their conditional dynamics have been harnessed to implement different quantum gates between spatially separated qubits [2]. The main drawback of existing protocols for communicating the information and implementing the gates via spin chains is the limitation in the number of users that can use the channel at each time. In most of these protocols [3], the desired operation can be established only between a pair of channel users. This critical limitation restricts the functionality of the quantum computers as operations between registers are fulfilled only sequentially.



Schematic of simultaneous quantum communication between multiple users across a spin-chain channel. By optimizing the local parameters including exchange coupling J_0, and local magnetic fields B_0 and B_α ($\alpha = 1,..,M$) multiple pairs can use the channel simultaneously. Besides, multiple entangling gates between arbitrary pairs can be applied through the common channel.

Here, we first propose a new protocol that allows multiple users to communicate simultaneously (in two ways) through a shared spin chain without crosstalk. The functionality of this communication protocol relies on mediating an effective interaction between each pair of channel users via a distinct set of energy eigenstates of the system achieving by modulating the Hamiltonian parameters appropriately. We introduce three strategies with different levels of Hamiltonian tuning; each might be suitable for a different physical platform. Next, we show that this protocol can also effectively and simultaneously implement multiple entangling gates between arbitrary pairs of remote qubits. Our protocol for communicating the information and implementing entangling gates is shown to be stable against various sources of imperfections and can be realized on superconducting quantum simulators [4].

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