Almost-perfect quantum-state transfer through a long uniform chain

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The natural dynamics of an open quantum chain of qubits can be exploited for transferring a quantum state between its ends. We use the general hopping model

$$\mathcal{H} = \frac{1}{2}\sum_{i=1}^{N-1} J_i \left(c_i^\dagger c_{i+1} + c_{i+1}^\dagger c_i \right) ,$$

that can be realized in several ways, such as a spin chain, an array of quantum dots or an optical lattice. Each site of the chain can be thought of as a 'qubit', i.e. an object endowed with a 2-dimensional Hilbert space of states generated by $|0\rangle$ and $|1\rangle$. Assuming that qubit 1 to be initially in the state $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$, the purpose is that the dynamics of the chain leads at some time the state of qubit N as close as possible to $|\psi\rangle$.

In a uniform chain ($J_i = J$) this quantum-transfer process is readily found to be impossible due the effect of dispersion, while a perfect transmission can occur if $J_i \propto \sqrt{i(N-i)}$. However, this setup is hardly realizable in a lab, so we consider a uniform chain and just allow $J_1 = J_{N-1}$ and $J_2 = J_{N-2}$ to differ from J.

We show that this setup gives more than 99 %-fidelity transfer, even when $N \to \infty$, provided that the extremal couplings have optimal values $J_1 \sim 2N^{-1/3}$ and $J_2 \sim 2^{3/4}N^{-1/6}$. The transmission time is ballistic, $t \simeq N/J$, and the quality of quantum transfer keeps being high in a large neighborhood of the optimal values, so there is no need to finely tune J_1 and J_2 in an experiment.