Realizing Topological Quantum Walks on NISQ Digital Quantum Computer

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Inventing Harmonious Future

We study quantum walks on the off-diagonal Aubry-André-Harper (AAH) lattice with periodic modulation using a digital quantum computer. Focusing on single-particle initial states at both the lattice edge and bulk, we explore the effects of hopping modulation and phase factors. The edge state demonstrates robustness, influenced by the topological nature of the AAH model, while a bulk-initiated quantum walk shows repulsion from the edge under strong modulation. Extending to two interacting particles, we observe edge-bulk repulsion and interaction-induced localization, analyzed through density evolution, two-particle correlation, and participation entropy.

Model and Approach

We study the QW of spinless fermions or hardcore bosons on a one-dimensional lattice, focusing on the interacting off-diagonal AAH model with periodic hopping modulation. The corresponding Hamiltonian is given by -

$$\hat{H} = \frac{J}{2}\sum_{i=1}^{N-1}\left[1+\lambda_J\cos\left(\frac{2\pi i}{T}+\phi_J\right)\right]\left(\hat{\sigma}_i^x\hat{\sigma}_{i+1}^x+\hat{\sigma}_i^y\hat{\sigma}_{i+1}^y\right)+\frac{V}{4}\sum_{i=1}^{N-1}(1-\hat{\sigma}_i^z)(1-\hat{\sigma}_{i+1}^z)$$

Here $\hat{\sigma}_i^k$ represents Pauli matrices (k=x,y,z) with eigenvalues ± 1. λ_J and ϕ_J are hopping Modulation strength and phase factor, respectively.

Our analysis focuses on cases where T is commensurate and an integer, specifically emphasizing on T = 2. Our studies focused on the continuous-time quantum walk, following the unitary time evolution of the time independent Hamiltonian given by

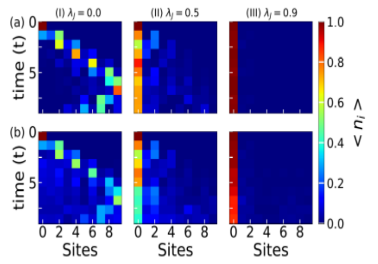
$$|\psi(t)\rangle = e^{-i\hat{H}t}|\psi(0)\rangle$$

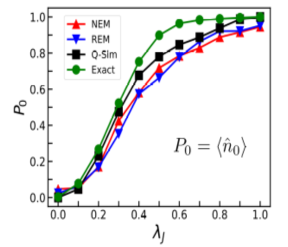
Quantum simulation on IBM quantum computers

In this study, we present outcomes from simulations conducted on the 127-qubit IBM "ibm_brisbane" instance. To benchmark our results, we compare them with those from an exact calculation ("Exact") and an ideal Qasm-simulator ("Q-sim") provided by Qiskit python API. To address potential errors from Hardware noise, we also employ readout error mitigation (REM)[3] using the Qiskit runtime [4] and Post-selection.

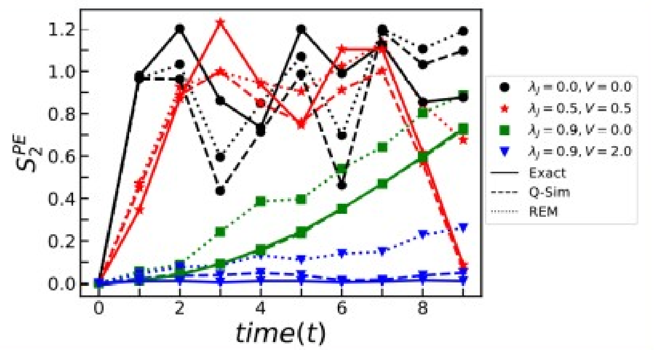
Results: Single Particle QW

Topological Edge State:





$$S_k^{PE}(t) = \frac{1}{1-k}\log\left(\frac{1}{N}\sum_{i=0}^{L-1}p_i(t)^k\right) \text{ [5]}$$



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