Adaptive Peierls Phase Modulation for Quantum State Routing in Multi-Photon Systems Under Decay and Disorder

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In quantum photonic systems, information can be encoded in the distribution of photons (Fock states) across sites at a time. This makes it important to have control mechanisms that guide photons and increase the probability of finding them in a desired state at a chosen time. Conventional approaches such as shortcut-to-adiabaticity and optimal control require precise parameter tuning and isolation from environmental effects, which is difficult in realistic systems. In practical photonic devices, losses (decay) and imperfections (disorder) disrupt photon transport and reduce performance. symmetry breaking by local TRSB has traditionally been used to introduce directional bias in photonic transport. In this work, we explore whether time-dependent phase modulation can enable adaptive quantum state routing in open systems. We modify the Bose–Hubbard Hamiltonian to include time-dependent phases ?(t) and model the system using a Lindblad master equation for a multi-site photonic network with realistic decay and disorder. A covariance-matrix adaptation evolution strategy (CMA-ES) is used to optimize phase profiles across time and bonds that maximize routing fidelity. Across test cases, the adaptive protocol consistently outperforms static control. For example, under realistic decay and disorder, fidelity improves from ~0.30 to ~0.70 (adaptive), while also enabling on-demand high-fidelity peaks at chosen times, including regions where static methods show near-zero fidelity. In the absence of decay, fidelity exceeds 0.9 across all tested cases. Since the approach requires only phase modulation, it can be implemented on existing integrated photonic platforms, providing a practical and scalable control strategy that can enhance existing photonic control methods.

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