Clifford-based Optimization of Graph State Generation Using Quantum Emitters

S. Ghanbari[1,2], J. Lin[1,3], B. MacLellan[4,5,6], L. Robichaud[1,3], P. Roztocki[6] and HK. Lo[1,2,3]

[1] *Quantum Bridge Technologies Inc., Toronto, Ontario M5G 0C6, Canada*
[2] *Department of Physics, University of Toronto, Toronto, Ontario M5S 1A7, Canada*
[3] *Department of Electrical and Computer Engineering, University of Toronto, Toronto, Ontario M5S 3G4, Canada*
[4] *Department of Physics and Astronomy, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada*
[5] *Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada*
[6] *Ki3 Photonics Technologies, Montreal, Quebec H1V 2Y8, Canada*

luc.robichaud@qubridge.io

Graph states are a family of highly entangled states that are an important resource for applications such as quantum communication [1] and computing [2, 3]. To realize these graph states, photonic platforms show promise as they offer advantages such as mobile photonic qubits, qubit stability due to weak interaction with their environment, and having support from a highly mature technology and infrastructure. However, generating photonic graph states remains challenging due to the lack of efficient two-qubit gates within linear optics for entangling two photons [7, 8, 9].

Deterministic sources such as quantum dots are a promising solution and have already been demonstrated to generate linear cluster states [4, 5]. 2D graph states, which are required for many applications, can be generated by entangling multiple emitters which pass on their entanglement to the emitted photons [6]. However, for quantum emitters to reach their full potential in photonic graph state generation, quantum circuits, which are the protocols used to generate a quantum state, must be optimized to reduce the number of experimentally difficult operations such as two-qubit gates.

In our work [10, 11], we have developed techniques using local Clifford equivalency and photon emission reordering to optimize quantum circuits which generate a target photonic graph state using quantum emitters. More specifically, by manipulating the desired graph using Local Clifford operations, which can be easily reversed, and the photons' emission ordering, we can generate a set of unique quantum circuits which generate the target state. These quantum circuits are then analyzed in terms of metrics such as the number of two-qubit gates. Applying our techniques to repeater graph states, we find quantum circuits which reduce the number of CNOTS by 50% compared to deterministic methods of finding a quantum circuit [12]. For large graph states, where the local Clifford and photon emission reordering orbits are too large to exhaustively search, we have developed guided search methods based on correlations between graph and circuit metrics. In the case of highly-connected 15-photon random graphs, we are able to reduce the number of unitaries by 65% and the maximum depth between emission events by 46%. Our techniques therefore significantly reduce the complexity of protocols, bringing quantum emitters such as quantum dots closer to the generation of photonic 2D graph states.

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