LNN Quantum Circuit of Toffoli Gate

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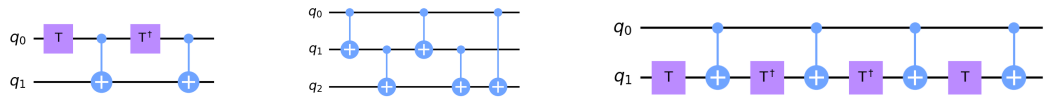
Abstract

In transpilation, a 3-qubit Toffoli gate (CCX) is decomposed into the basis gates of the target device and gates are properly mapped into device gates. However, in the mapping phase of transpilation it may require inserting SWAP gates in the circuit which results in a circuit with increased CX ($Controlled - NOT$) gate count. Note that CX gate operations to perform on a noisy quantum device are expensive and error prone, therefore, circuits are optimized with different levels of optimization in transpilation. This report presents an Linear Nearest Neighbour (LNN) quantum circuit of Toffoli gate. This circuit can potentially be used in the decomposition phase to leverage the mapping process for specific target devices. Experiments show promising results, however, it requires experimenting further with considering different constraints of physical devices.

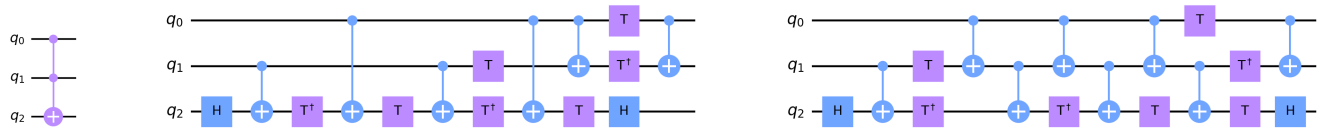
I. Quantum Decomposition of Toffoli Gate

WHEN 2-qubit gates in a circuit are not LNN, usually SWAP gates are inserted to make them LNN. However, a template based transformation with fewer gates is reported in [1]. Templates are identity circuits that can be used to transform and optimize circuits by using template matching algorithm [2]. Consider the quantum templates in Figure 1. With these templates, applying LNN transformation and further optimization for the input circuit in Figure 2(b) results in the LNN circuit in Figure 2(c).



(a) (b) (c)

Fig. 1: Quantum templates



(a) cxx gate (b) Standard decomposition of CCX (c) LNN decomposition of CCX

Fig. 2: Decomposition of CCX gate

For performance analysis, IBM Qiskit framework is used to run transpilation [3] by setting 4 levels of optimization [4] and scheduling ($scheduling\_method =$ "$asap$") for the both circuits. The gate count, number of operations and timelines from the level-4 optimization are shown in Appendix A and B. The results in Appendix A show that for the standard quantum CCX, the output circuit has 9 CX gates whereas for the LNN quantum CCX, it has 8 CX gates. Moreover, it improves the execution time shown in Appendix B. Experiments with benchmarks and in-depth analysis are on progress.

References

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[3] Qiskit contributors, "Qiskit: An open-source framework for quantum computing," 2023.

[4] G. Li, Y. Ding, and Y. Xie, "Tackling the qubit mapping problem for nisq-era quantum devices," 2019.

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APPENDIX A
DEPTH, GATE COUNT AND NUMBER OF OPERATIONS OF TRANSPILED CIRCUITS

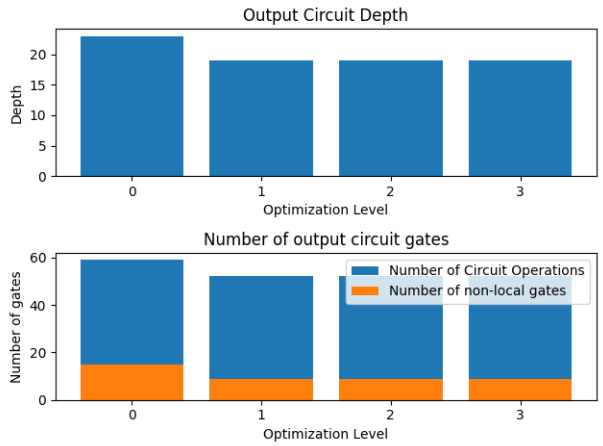

Fig. (a): For standard quantum CCX gate

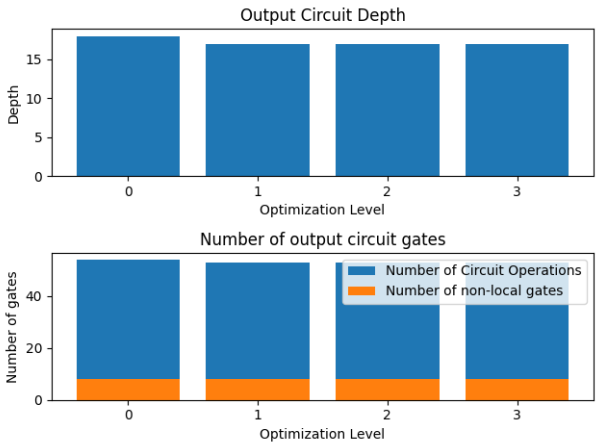

Fig. (a): For LNN quantum CCX gate

TABLE I: Comparison of depth and gate count, operations of standard and LNN quantum Toffoli gate

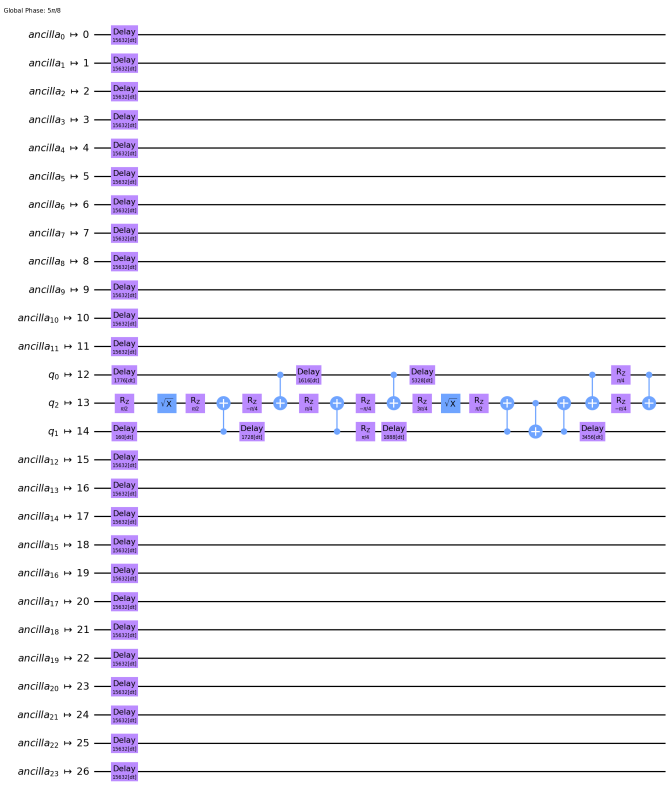

Fig. (b): For standard quantum CCX gate

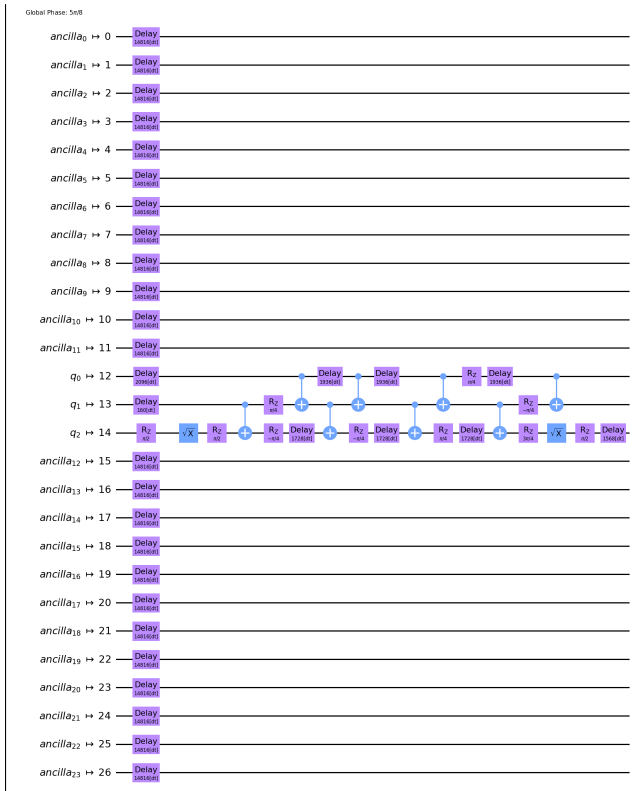

Fig. (b): For LNN quantum CCX gate

TABLE II: Comparison of qubits mapping of standard and LNN quantum CCX gate

APPENDIX B
TIMELINES OF TRANSPILED CIRCUITS

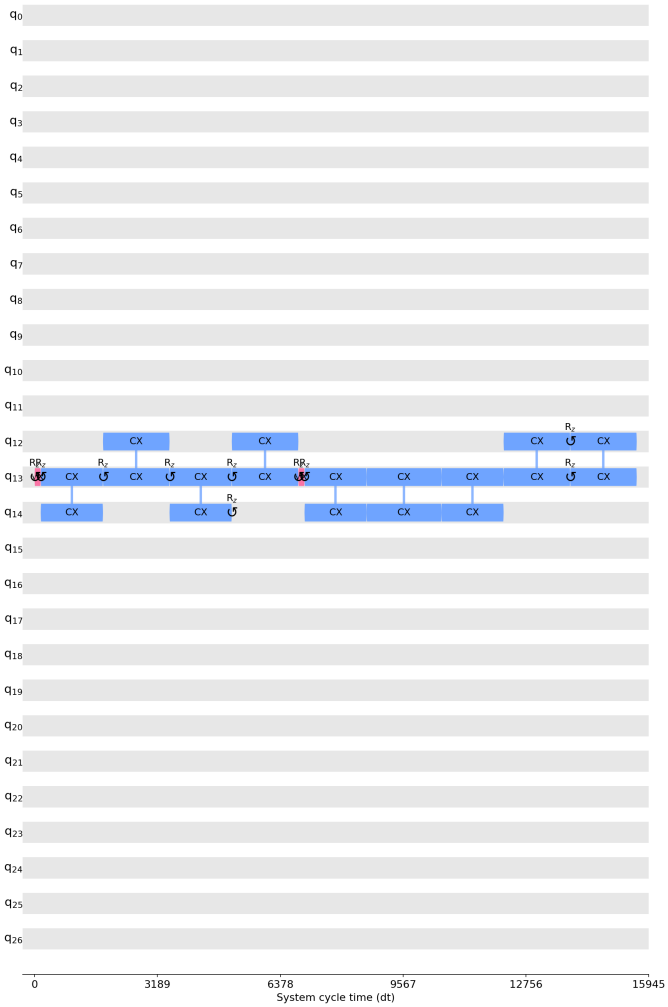

Fig. (a): For standard quantum CCX

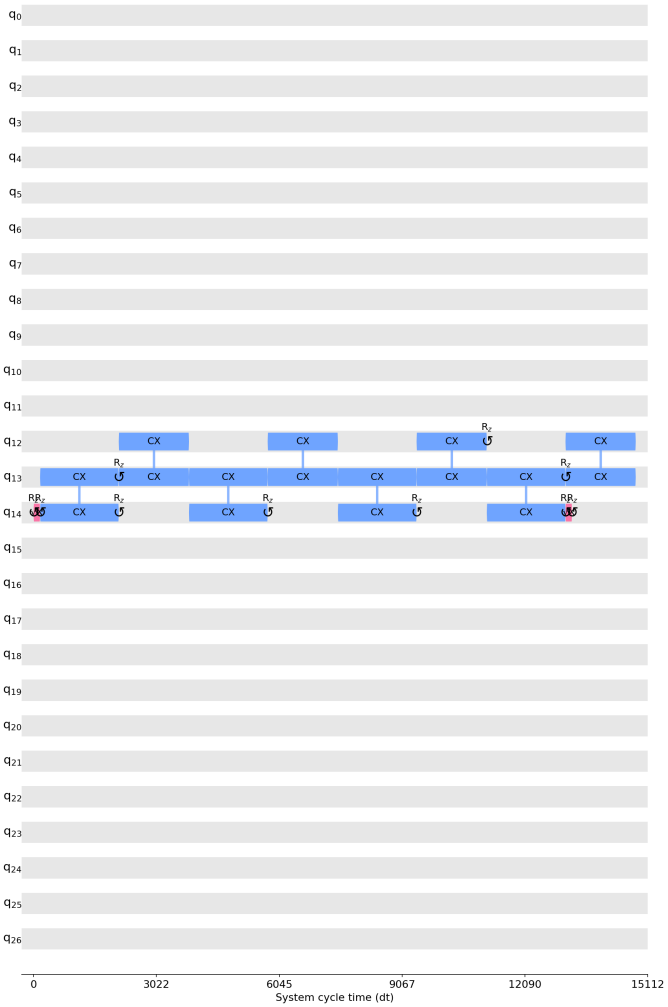

Fig. (a): For LNN quantum CCX

TABLE III: Comparison of timelines of standard and LNN quantum CCX gate