A Hardware-aware Heuristic for the Qubit Mapping Problem in the NISQ Era

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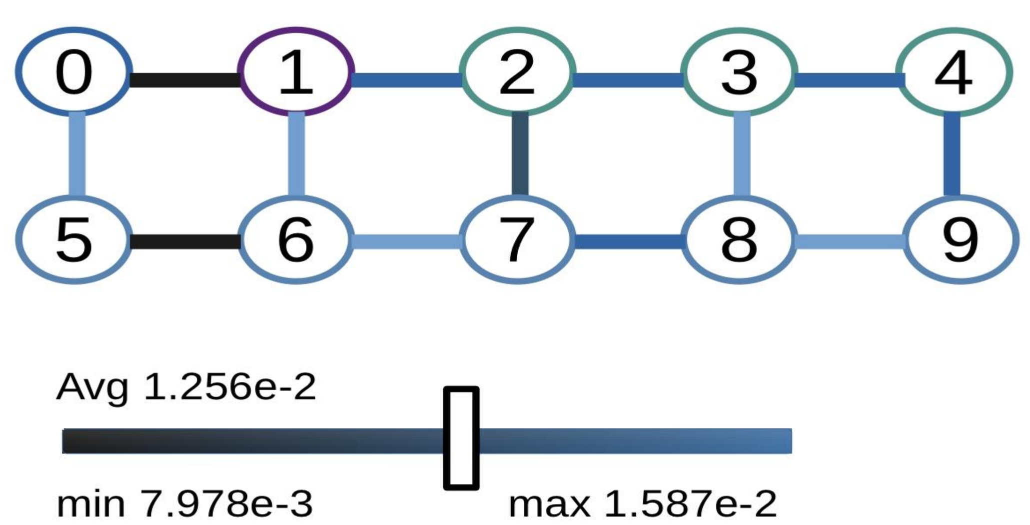
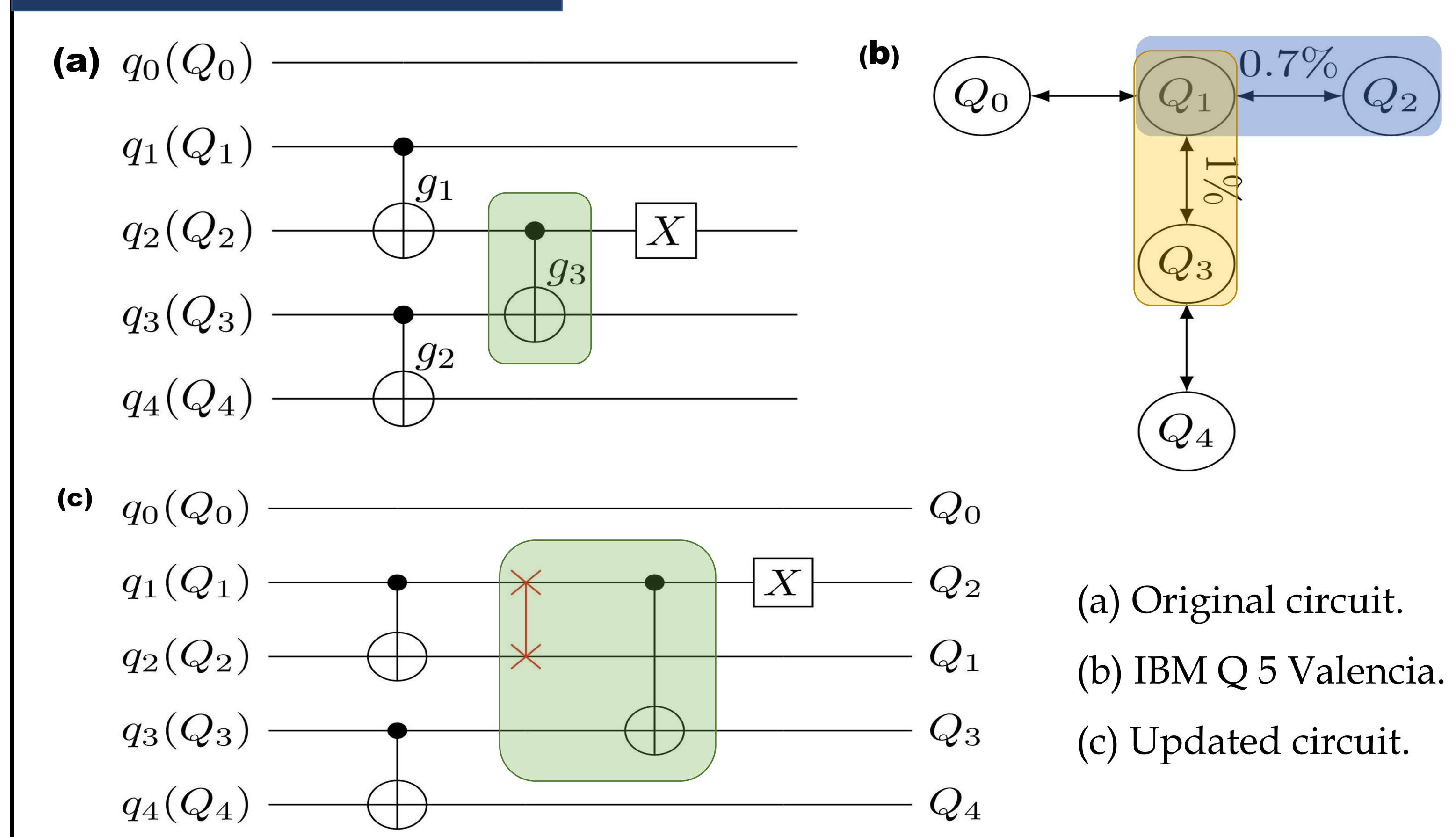
Introduction



- NISQ devices.
- Connectivity constraint: Nearest-neighbor connections.
- Different physical qubits: various calibration data.
- Qubit mapping problem: Adapting a quantum program to given hardware connectivity.

Motivation



(a) Original circuit.
(b) IBM Q 5 Valencia.
(c) Updated circuit.

- Initial mapping
  - $\{q_0 \rightarrow Q_0, q_1 \rightarrow Q_1, q_2 \rightarrow Q_2, q_3 \rightarrow Q_3, q_4 \rightarrow Q_4\}$
- SWAP candidates:
  - $\{q_1, q_2\}$ and $\{q_1, q_3\}$
- Choose $\{q_1, q_2\}$ because of the lower error rate.
- Final mapping
  - $\{q_0 \rightarrow Q_0, q_1 \rightarrow Q_2, q_2 \rightarrow Q_1, q_3 \rightarrow Q_3, q_4 \rightarrow Q_4\}$

Methods

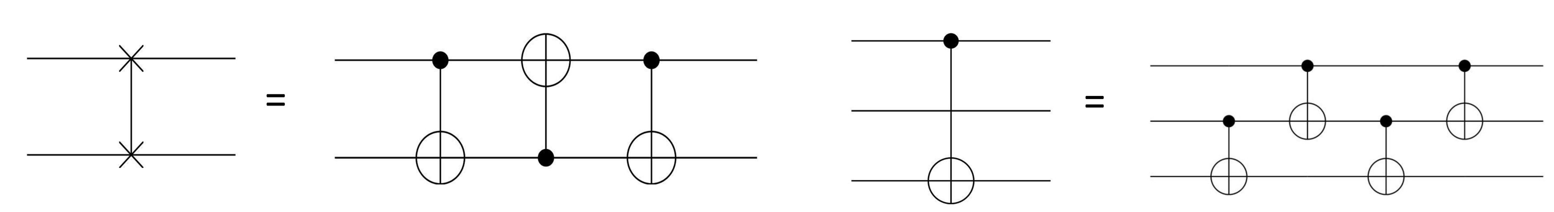
- Hardware-Aware (HA) mapping transition algorithm.
  - Cost function

$$H = \frac{1}{|F|}\sum_{g\epsilon F} D[\pi(g.q_1)][\pi(g.q_2)] + W \times \frac{1}{|E|}\sum_{g\epsilon E} D[\pi(g.q_1)][\pi(g.q_2)]$$

  - Distance matrix

$$D = \alpha_1 \times S + \alpha_2 \times \varepsilon + \alpha_3 \times T$$

    - S: SWAP matrix, ε: SWAP error matrix, T: SWAP execution time matrix
- Selection between SWAP and Bridge gate.

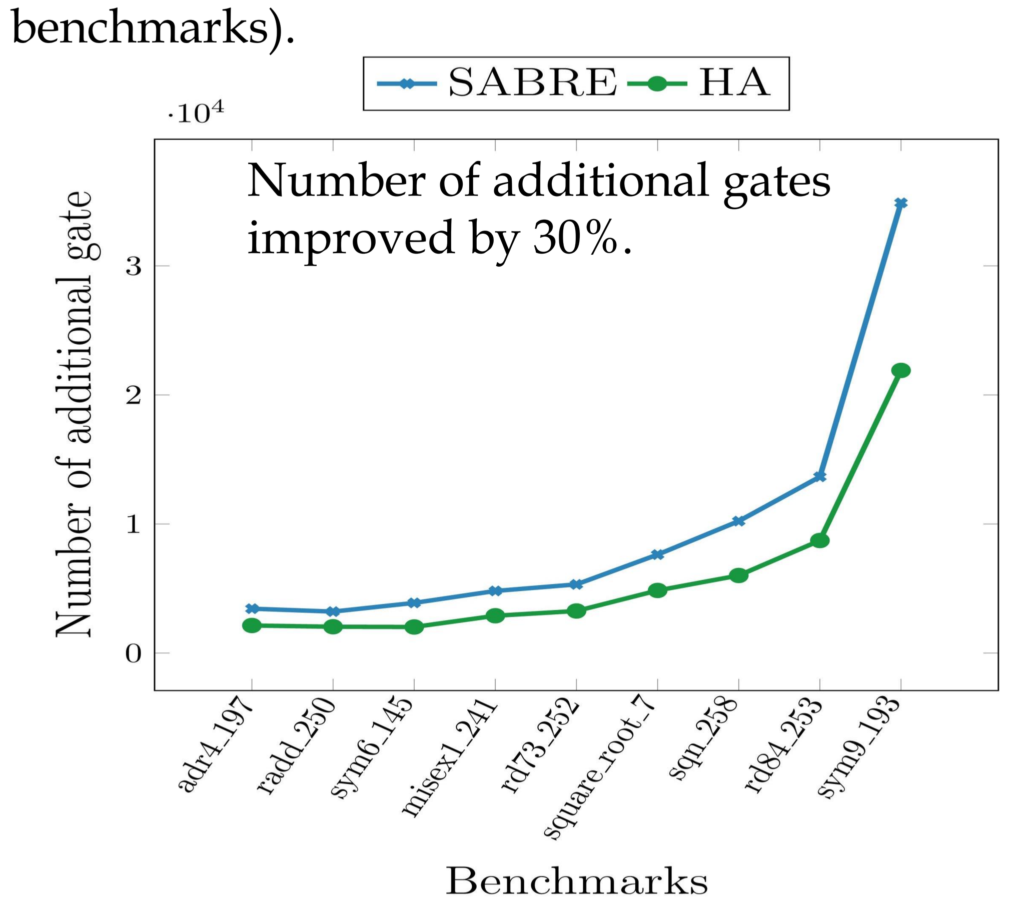


SWAP gate **Bridge gate**

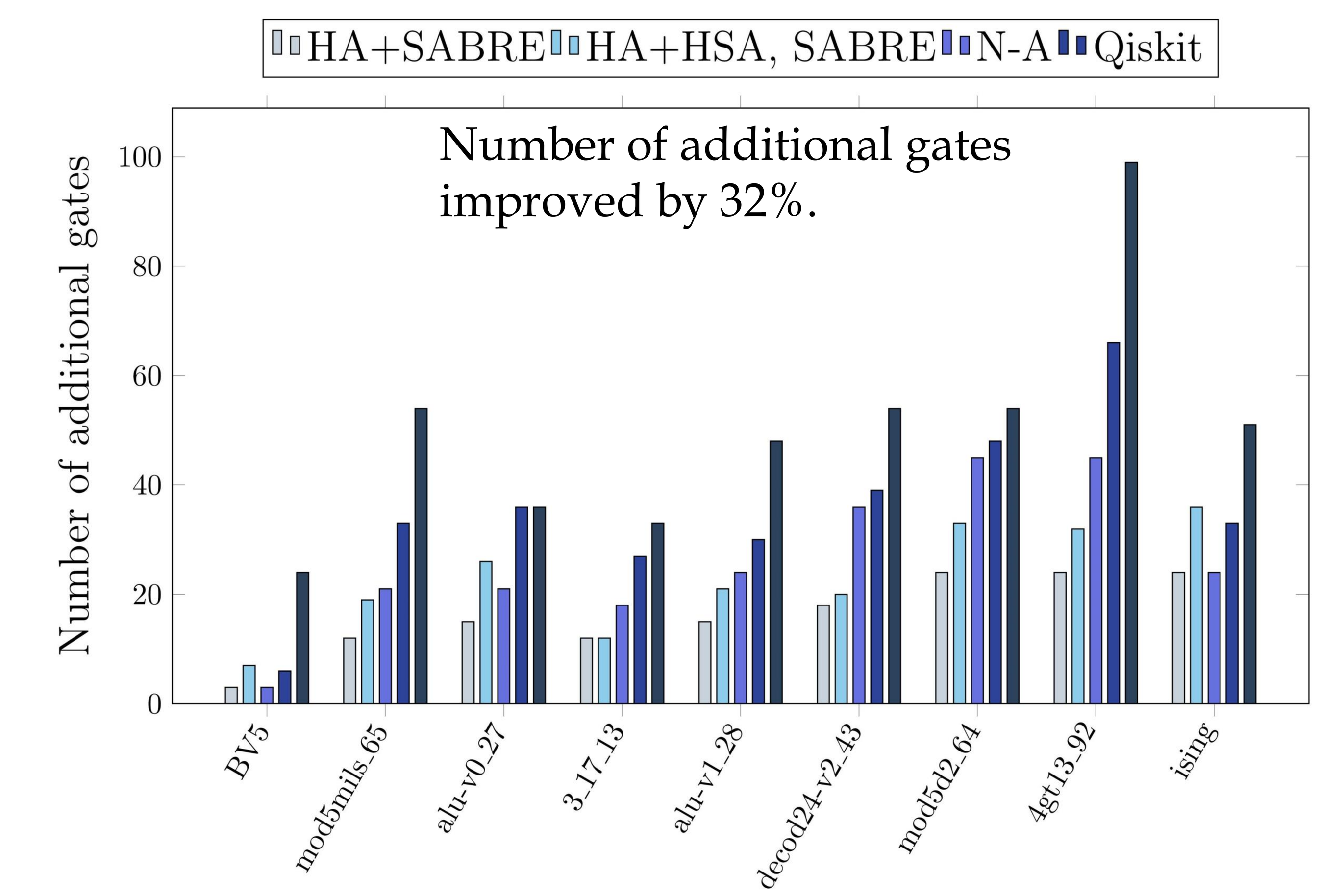
- Hardware-aware Simulated Annealing (HSA) initial mapping.
  - Hardware-aware **get_neighbor** method.

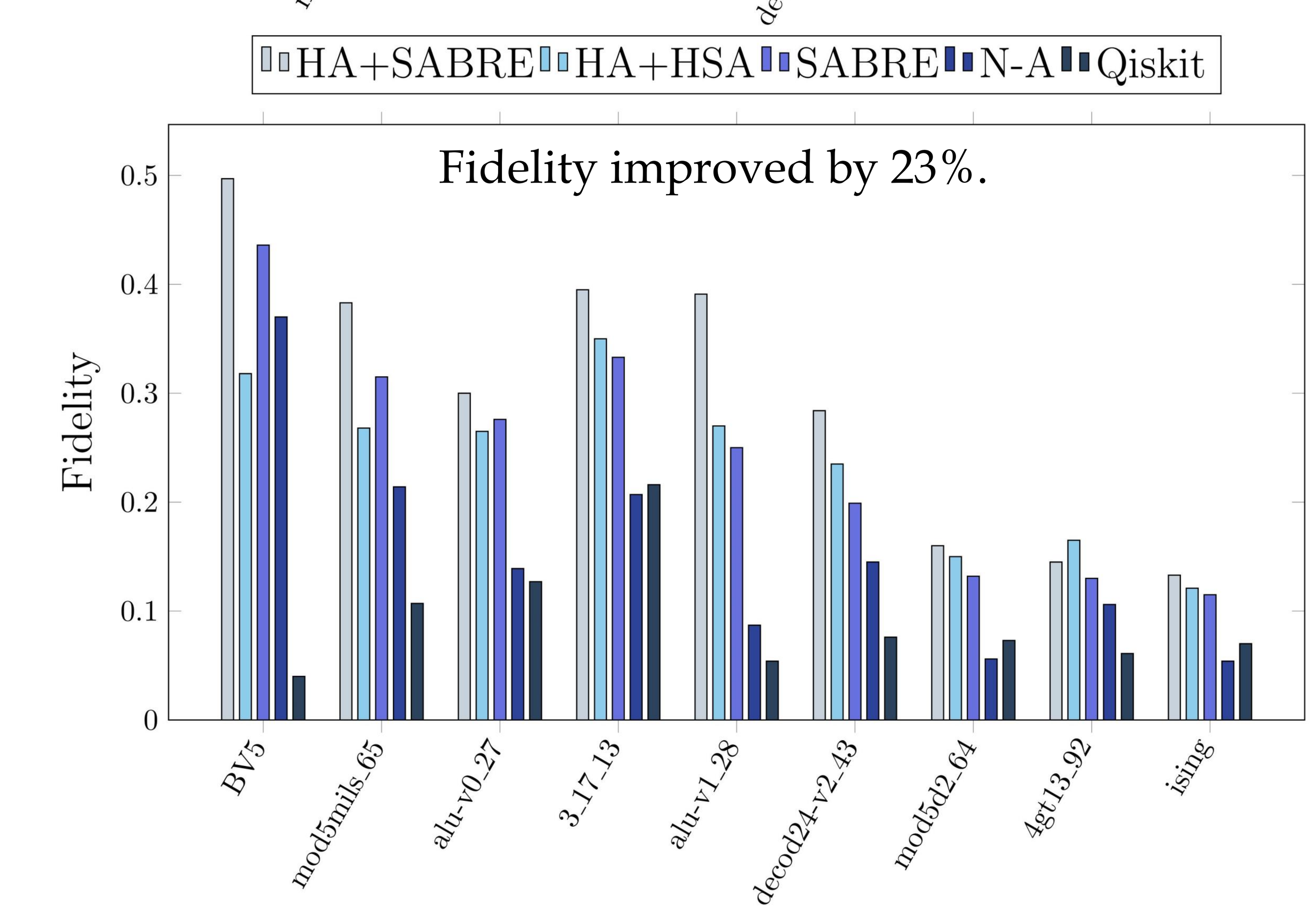
Results

- Comparison of number of additional gates on IBM Q 20 Almaden (large benchmarks).



- Comparison of number of additional gates and fidelity on IBM Q 20 Almaden (small benchmarks).





Conclusion

- Map the most used qubit of the mapped circuit to the most connected physical qubit.
- Apply CNOT gates on qubits that are directly connected and with reliable interconnects.
- If a CNOT cannot be applied on two neighbor qubits, apply on two qubits whose distance is two.

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