Feasibility of Distributed Measurement-Based Quantum Computing in Quantum Data Centers

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Abstract: We evaluate entanglement requirements, preparation, and execution times for QFT and Grover algorithms in distributed measurement-based quantum computation, and compare them with gate-based implementations on modular superconducting architectures, identifying regimes where measurement-based approaches outperform gate-based ones.

1. Introduction

Scaling quantum computing beyond single processors motivates distributed quantum computing architectures (DQC), where computation is performed across multiple interconnected quantum nodes. Such systems can be viewed as quantum data centers (QDCs) that integrate quantum processors through quantum and classical communication channels. Most work on DQC focuses on distributed gate-based quantum computing (DGB) [3]. While DGB effectively suffers from high overhead for remote gate operations, particularly CNOT gates, which require additional qubits, long entanglement generation times, and careful scheduling of communication qubits [1]. These factors increase execution latency and limit scalability. Measurement-based quantum computing (MBQC) offers an alternative model for DQC, where computation proceeds via local measurements on pre-shared cluster states [4]. This model decouples entanglement generation from computation and reduces gate-level coordination. Although MBQC has been studied in other contexts, its performances in distributed quantum architectures remain underexplored.

We consider a QDC architecture in which each node hosts a grid-based cluster state connected via quantum channels as illustrated in Fig.1.(a). While MBQC requires more physical qubits than DGB for logical operations (As an example shown in Fig.1.(b) and (c) which show CNOT gate in MBQC and gate-based formats.), its one-way execution model enables qubit reuse across computation cycles (see Fig.1.(d)) and avoids dynamic scheduling when feed-forward is not required, mitigating qubit-count limitations.

In this work, we present a system-level analysis of distributed MBQC (DMBQC) within a QDC abstraction. We model entanglement links, state preparation time, and execution time for the Quantum Fourier Transform (QFT) and Grover's search algorithm, and compare the results against DGB. Our results show that despite its higher number of entanglement links, DMBQC shows a lower execution time for both algorithms, while DGB benefits from lower initial state preparation time, identifying regimes where MBQC provides an advantage over DGB.

2. Methods

We compare DGB and distributed DMBQC as a function of the number of logical qubits, sweeping problem sizes from 10 to 50 qubits, and explicitly accounting for the number of entanglement links required to connect nodes in each paradigm. The hardware is modeled as a modular superconducting architecture with a fixed number of qubits per node. For DGB, nodes are assumed to be connected in a full-mesh topology, while for DMBQC a two-dimensional grid is assumed to enable the preparation of a full 2D Ising cluster state. Two-qubit interactions are

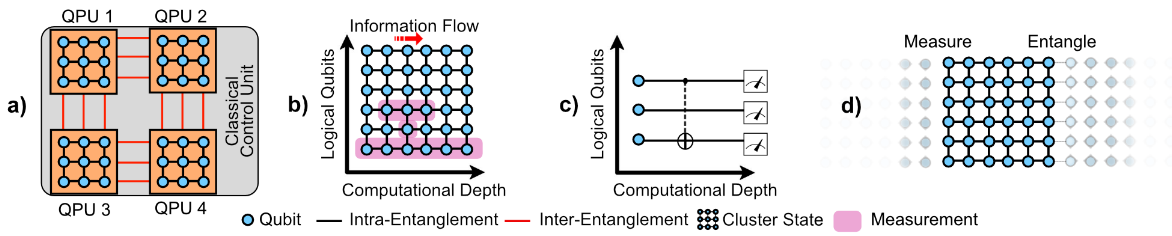

Fig. 1. (a) Architecture of DMBQC within a DQC. (b) CNOT gate implementation in MBQC. (c) CNOT gate implementation in DGB. (d) Conveyor-belt property of MBQC

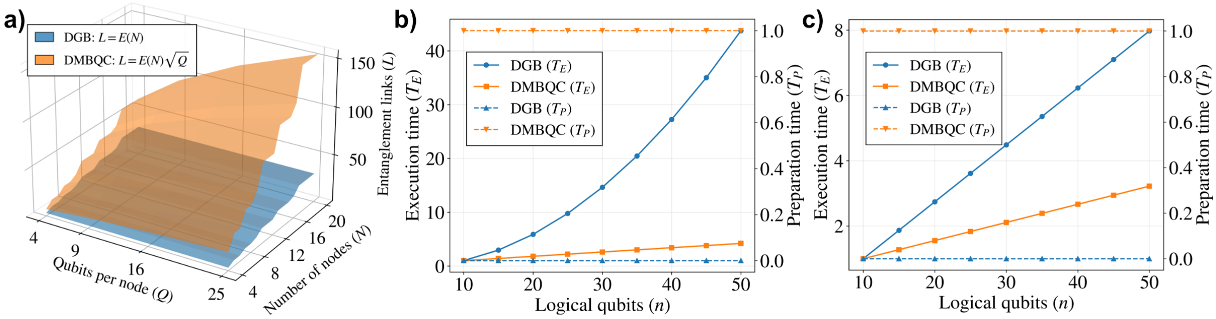

Fig. 2. (a) Entanglement links for DGB and DMBQC as a function of the node count, and qubits per node. Normalized preparation and execution time scaling for (b) QFT and (c) Grover's search, respectively.

classified as local or remote based on node membership, with remote interactions incurring additional latency to capture the cost of inter-node entanglement distribution.

Our analysis focuses on the quantum Fourier transform and Grover's search algorithm, chosen as representative benchmarks due to their central role in quantum algorithms. For each problem size, gate counts and interaction locality are determined algorithmically from the modular mapping. Execution and preparation costs are then evaluated using a simplified timing model that distinguishes single-qubit operations, local two-qubit operations, remote two-qubit operations, and layered measurement-based execution in the DMBQC case.

Preparation overhead is treated separately from execution. Gate-based execution assumes negligible preparation cost, whereas measurement-based execution includes a fixed overhead associated with resource-state generation. All results are normalized to the smallest problem size to emphasize relative scaling behavior rather than absolute runtimes. Complete definitions, equations, parameter values, and implementation details are provided in the accompanying open-source code [2].

3. Results

Fig.2.(a) summarizes the hardware requirements for DGB and DMBQC as a function of node count, inter-node entanglement links, and qubits per node. Across all system sizes, DMBQC exhibits a higher density of entanglement links, reflecting the structured connectivity required to support 2D Ising cluster states. This overhead is largely independent of the number of qubits per node, indicating that global connectivity, rather than local capacity, is the dominant resource. In contrast, the full-mesh connectivity assumed for DGB results in fewer inter-node links but places stronger demands on remote gate execution during computation.

Fig.2.(b) and (c) compare normalized execution and preparation scaling for the QFT and Grover's search algorithm, respectively. For both algorithms, DMBQC shows a slower growth of execution time with problem size, driven by measurement-layer depth rather than the accumulation of remote two-qubit operations. While DMBQC includes a fixed preparation overhead, this cost becomes comparatively less significant as system size increases. The separation is more pronounced for the QFT due to its dense interaction structure, whereas Grover's algorithm exhibits a similar trend with a reduced slope.

4. Conclusion

Our results show that despite higher hardware overhead, DMBQC achieves lower execution time for both algorithms, while DGB benefits from lower initial state preparation time. This trade-off highlights distinct operating regimes where MBQC provides architectural advantages for distributed quantum data centers. These findings position MBQC as a competitive and scalable alternative to DGB.

Acknowledgments:

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References

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