Generation of Large-Scale Entanglement on Physical Quantum Devices

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Entanglement is typically seen as the essence of what differentiates quantum behaviour from classical [1] and multi-qubit entanglement can be thought of as a unique resource that is at the core of quantum computing [2]. The generation and verification of entanglement over multiple qubits is central to challenging our understanding of entangled states and quantum information processing, and can be used as a benchmark for Noisy Intermediate Scale Quantum (NISQ) devices. Thus, it is a topic of intense interest as quantum computing hardware advances. We investigate the ability to generate two forms of entanglement in IBM Quantum devices, bipartite entanglement, where the state is inseparable with respect to all bipartitions of qubits, and the stronger genuine multipartite entanglement (GME), where the state always contains inseparable pure states spanning all its qubits. In our first work we prepared GHZ states on the 27-qubit *ibmq_montreal* device and measured their fidelities to detect GME and to observe the effects of parity checking qubits for error detection. We successfully certified GME on a prepared 27-qubit Greenberger-Horne-Zeilinger (GHZ) state over the full device [3]. In our second work we prepared graph states over all qubits of three IBM Quantum devices of sizes 20, 53 and 65 qubits and showed that they were each fully bipartite entangled [4,5].

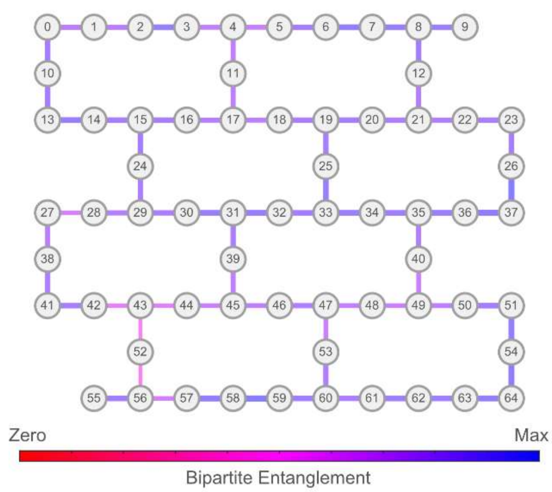

Figure 1: The level of bipartite entanglement measured between each adjacent pair of qubits of a prepared graph state spanning the full 65-qubit *ibmq_manhattan* device.

[1] R. Horodecki, P Horodecki, M. Horodecki and K. Horodecki, *Rev. Mod. Phys,* 81, 2 865 **(2009)**

[2] R. Raussendorf, and H. J. Briegel, *Physical Review Letters*, 86, 22 5188 **(2001)**

[3] G. J. Mooney, G. A. L. White, C. D. Hill, and L. C. L. Hollenberg, J. Phys. Commun **(2021)**

[4] G. J. Mooney, G. A. L. White, C. D. Hill, and L. C. L. Hollenberg, Adv. Quantum Technol. **(2021)**

[5] G. J. Mooney, C. D. Hill, and L. C. L. Hollenberg, Sci. Rep. **(2019)**