Distributed Quantum Computation on Continental Scales Operates on Kilohertz Clock Cycle with Quantum Satellite Networks

An Extended Abstract

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Networking quantum computers over vast distances for distributed quantum computation is a fascinating problem, but much work remains to be done in order to characterise the resource requirements for such networks. Because unknown quantum information cannot be perfectly copied, it is necessary to send sensitive qubits between machines for processing. The most robust way to do this is to perform quantum state teleportation, which requires shared entanglement. Despite recent advances in repeater network schemes, long distance entanglement distribution remains a challenge. Using satellites to distribute maximally entangled photons (Bell pairs) between distant stations is an intriguing alternative. This is known to be a viable strategy for quantum key distribution [Yin+17] [Bon+09], however the question of if a quantum satellite network is feasible for distributed quantum computation (DQC) remains open.

The objective of this paper is to establish the conditions under which a DQC application is tractable when entanglement is supplied from a quantum satellite network. We quantify this by determining the rate at which logical Bell states can be produced between surface code embeddded qubits as this rate imposes a hard limit on the system's clock speed. The computational problem we target is fast RSA decryption – a quintessential example of a large scale computation. We choose the surface code as our logical qubit encoding due to its high physical error tolerance, inexpensive two qubit operations via lattice surgery, and because it is the preferred technique today for large-scale architectures [Fow+12] [Kri+21]. We make several generous simplifications by assuming photon capture is lossless, that arriving photons are always coincident, and that quantum memories are free. Our network model is adapted from Khatri et. al. [Kha+21] who develop a constellation of around 400 satellites designed to supply continuous global coverage while maximizing their chosen figure of merit: The ratio of average entanglement distribution to the total number of satellites. We estimate the maximum entanglement throughput possible for a satellite by surveying the power ratings of commercial communication satellites, and identifying the brightest Bell pair source. From this, and other considerations such as purification, we determine the rate at which logical Bell pairs can be produced given the average gate time of the architecture and the distance required to traverse. Our results show that RSA factorization over state distances (500-999 km) is possible in a matter of hours while continental (1000-4999 km) and transcontinental (5000+ km) distances require on the order of months and years respectively.

References

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