Noise tolerant entanglement verification in an untrusted quantum network

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Entanglement verification is a key aspect of modern quantum communication protocols. In a modern quantum network composed of several individual sources of correlated particles, neighbouring nodes link via entanglement swapping, giving rise to distributed entanglement between particles with no common history [1]. One means of entanglement verification in such a network is a Bell test, whereby pairs of correlated particles are measured and the statistics compared against local hidden variable models – this test allows entanglement to be verified even if the nodes are untrusted [2]. In the past [3], quantum networks relied on Bell tests between these distributed nodes, with success demanding an entanglement visibility of $v > 0.707$ - a challenging requirement from a practical standpoint. In this work, we construct a simple three-node quantum network, powered by two independent entangled photon sources. Using this network, we test a newly derived Bell-like inequality [4,5], considering not only the measurement outcomes of the distributed entanglement on the final nodes, but also the necessary intermediate node as well. We experimentally violate this noise-tolerant tri-partite inequality for the first time, demonstrating entanglement verification in an untrusted network that would work up to an entanglement visibility of only $v > 0.50$ given true Bell state measurements, and $v > 0.66$ given an imperfect Bell state measurement constructible using only linear-optics and post-selection. We violate both of the inequalities experimentally, demonstrating for the first time a more noise tolerant entanglement verification between untrusted nodes of a quantum network than the standard Bell test. This noise reduction is predicated by the addition of an assumption of independence of the photon sources [4,5] – a property we ensure given our experimental apparatus, and a property that will naturally arise in any future large-scale quantum network.

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