Quantum Computation and Quantum Communication with Entangled Photons

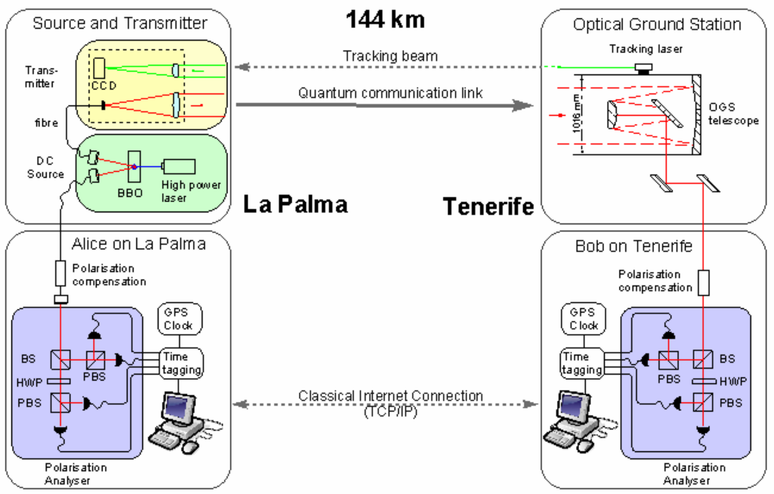
Anton Zeilinger

IQOQI Institute of Quantum Optics and Quantum Information, Austrian Academy of Sciences, & Faculty of Physics, University of Vienna

Entanglement is a fundamental resource both in long-distance quantum communication and in quantum computation. Because of its obvious indispensability in quantum teleportation, entanglement is crucial for quantum repeaters. Recently [1], we were able to synchronize two completely independent sources of entangled photons such that entanglement swapping became possible with independent lasers with high fidelity. In a future experiment, such lasers can be separated by kilometer distances.

In quantum cryptography, entanglement brings the advantage of obvious security. Entanglement-based quantum cryptography has now reached a rather mature stage. Most recently, we were able to demonstrate the robustness of polarization entanglement for long-distance quantum key distribution in telecom fibers of a length of the order of 100 km. In a parallel development, it was possible to distribute entangled photons over a distance of 144 km in free space between two Canary Islands [2] (Figure 1).

Figure 1

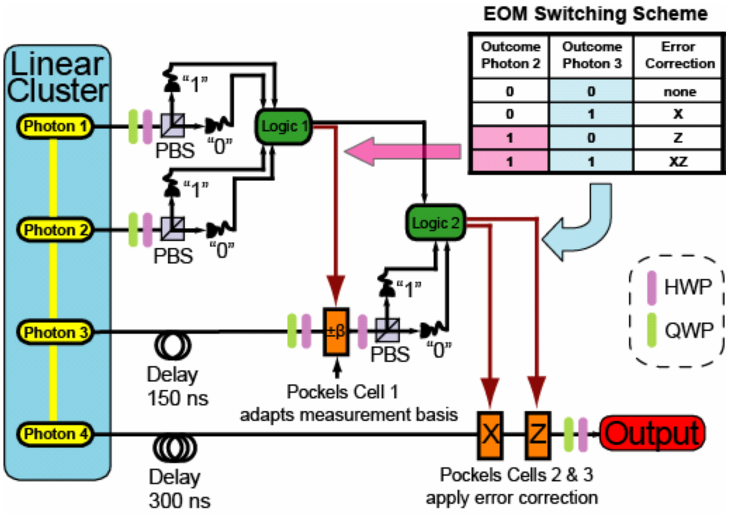


Entanglement-based quantum cryptography over 144 km between the Canary Islands of La Palma and Tenerife. One photon is measured locally by Alice on La Palma, the other one is sent over through telescopes to Bob on Tenerife. The quality of the link could be demonstrated by testing a CHSH inequality with a Bell S-value of S = 2,508 ± 0,037, which significantly violates the classical limit of 2. The qubit error rate of the link was 4,8% and 178 secret bits were obtained in a measurement time of 75 seconds.

In quantum computation, cluster states provide a new application of entanglement, particularly in all-optical schemes. This was made possible by the discovery of one-way quantum computation [3], where the measurement errors caused by the statistical nature of quantum measurement can be corrected by active feed-forward. Recently [4], we were able to implement active feed-forward into an earlier four-photon cluster state machine [5] (Figure 2).

Anton Zeilinger, "Quantum Computation and Quantum Communication with Entangled Photons," Coherence and Quantum Optics IX, N. P. Bigelow, J.H. Eberly, and C.R. Stroud, Jr., eds.

Figure 2



One-way quantum computation with active feed-forward. A concatenated sequence of measurements is able to correct errors produced by measurement in a photonic cluster state arrangement. The output of the measurement on two photons is fed forward to adapt the measurement basis on photon 3 using a Pockels cell. A further logic step allows a correction of Pauli errors on photon 4. Thus, all-optical quantum computation becomes deterministic.

There, Pockels cells were used to correct both for errors in the measurement basis and for Pauli errors. Furthermore, the scheme was actually concatenated with two corrections following each other. The most significant result here is that the cycle time, which includes the measurement itself, the feed-forward and the setting of the correct parameter on the Pockels cell was of the order of 150 nanoseconds, which is significantly faster than any cycle time in any other quantum computation scheme at present. Furthermore, the fidelity of the cluster state machine itself was of the order of 99% including the quality of the feed-forward. Future challenges certainly include the development of better sources for photonic cluster states and better detectors.

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