Nanophotonic platform boosts efficiency of nonlinear-optical quantum teleportation

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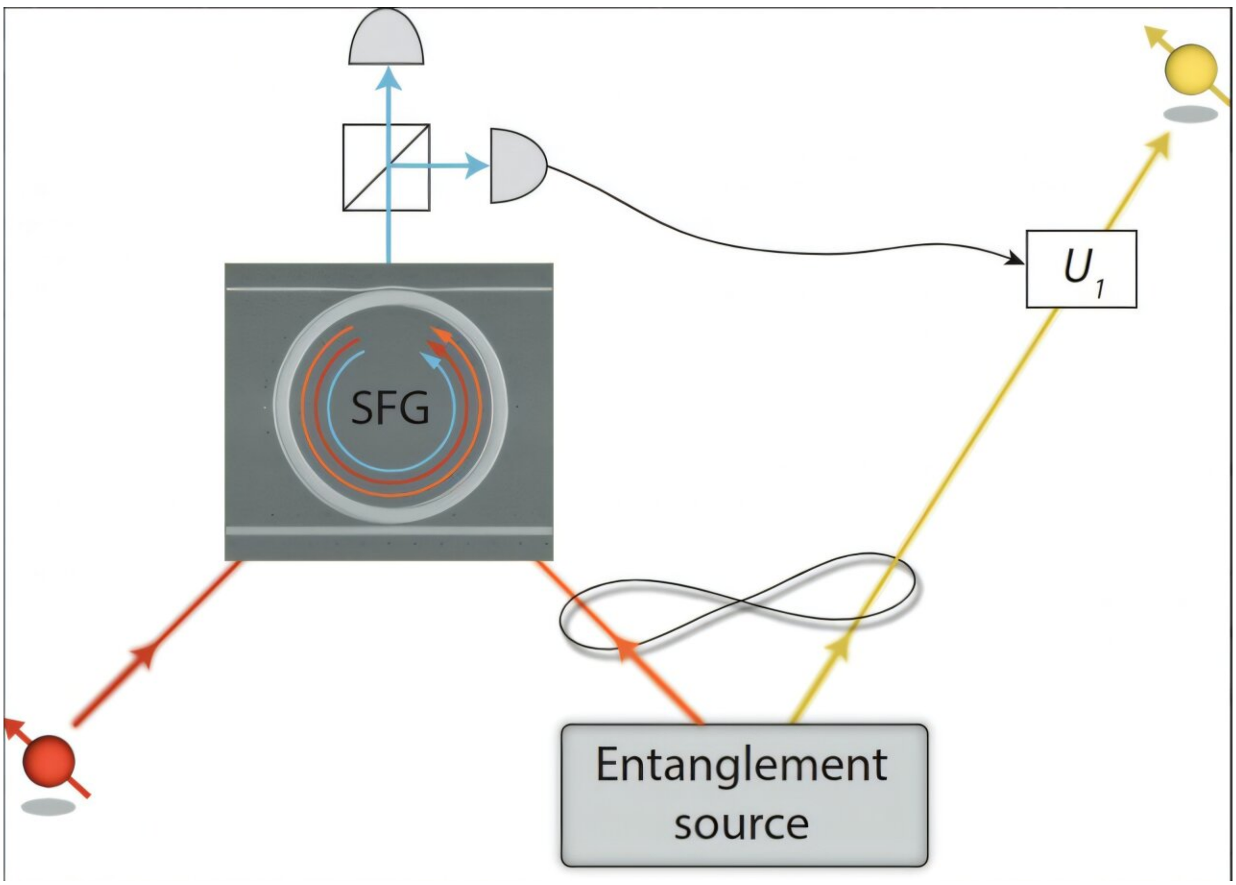

Quantum teleportation with nonlinear sum frequency generation (SFG). The nonlinear nanophotonic platform greatly mitigates multiphoton noise and leads to high teleportation fidelity. Credit: *Physical Review Letters* (2025). DOI: 10.1103/PhysRevLett.134.160802

Researchers have long recognized that quantum communication systems would transmit quantum information more faithfully and be impervious to certain forms of error if nonlinear optical processes were used. However, past efforts at incorporating such processes could not operate with the extremely low light levels required for quantum communication.

Now, a team at the University of Illinois Urbana-Champaign has improved the technology by basing the nonlinear process on an indium-gallium-phosphide nanophotonic platform. The result is substantially more efficient than prior systems, meaning that it requires much less light and operates all the way down to single photons, the smallest unit of light. For the first time, there is a path forward to making quantum communication systems with nonlinear optics feasible.

"Our nonlinear system transmits quantum information with 94% fidelity, compared to the theoretical limit of 33% on systems using linear optical components," said Kejie Fang, an Illinois professor of electrical and computer engineering and the project lead. "This alone demonstrates the power of quantum communication with nonlinear optics. The big problem to solve is efficiency. By using a nanophotonic platform, we saw the efficiency increase by enough to show that the technology is promising."

This research was recently published in the journal *Physical Review Letters*.

Transmission of quantum information over networks is facilitated by the quantum teleportation protocol. In it, the phenomenon of quantum entanglement—in which two quantum objects, typically single photons, influence each other even when there is no apparent physical connection between them—is exploited to transfer quantum information between a sender and a receiver without transmitting it through a communication channel. The advantage of this procedure is that the influences of external noise and channel imperfections are greatly mitigated.

There are two factors which limit the performance of quantum teleportation. First, the use of standard, linear optical components introduces inherent ambiguities in the transmission. Second, the entangled photons are made with an imperfect process subject to errors and excess noise. In particular, it is common for entanglement sources to produce more than a single pair of photons at once, making it unclear whether the two used in teleportation are truly entangled.

"Multiphoton noise occurs in all realistic entanglement sources, and it's a serious problem for quantum networks," said Elizabeth Goldschmidt, an Illinois professor of physics and a co-author of the study. "The appeal of nonlinear optics is that it can mitigate the effect of multiphoton noise by virtue of the underlying physics, making it possible to work with imperfect entanglement sources."

Nonlinear optical components cause photons of different frequencies to combine and create new photons at new frequencies. For quantum teleportation, the nonlinear process used is "sum frequency generation" (SFG), in which the frequencies of two photons add to form a new photon. However, the original two photons must have specific starting frequencies for the process to occur.

When SFG is used in quantum teleportation, the protocol does not proceed if two photons of the same frequency are detected. This filters out the primary type of noise in most entangled photon sources and allows for much higher teleportation fidelities than would be possible otherwise. The main drawback is that an SFG conversion occurs with very low probability, making the teleportation process highly inefficient.

"Researchers have known about this for a long time, but it was not fully explored due to the low probability of successful SFG," Fang said. "In the past, the best that was achieved is 1 in 100 million. Our achievement is realizing a factor of 10,000 increased conversion efficiency to 1 in 10,000 with a nanophotonic platform."

The researchers are optimistic that, with further development, quantum teleportation with nonlinear optical components can be made even more efficient. They believe that it will find use in other quantum communications protocols, including entanglement swapping.

More information: Joshua Akin et al, Faithful Quantum Teleportation via a Nanophotonic Nonlinear Bell State Analyzer, *Physical Review Letters* (2025). DOI: 10.1103/PhysRevLett.134.160802. On *arXiv*: DOI: 10.48550/arxiv.2411.15437

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