Scientists demonstrate quantum nature of entanglement swapping

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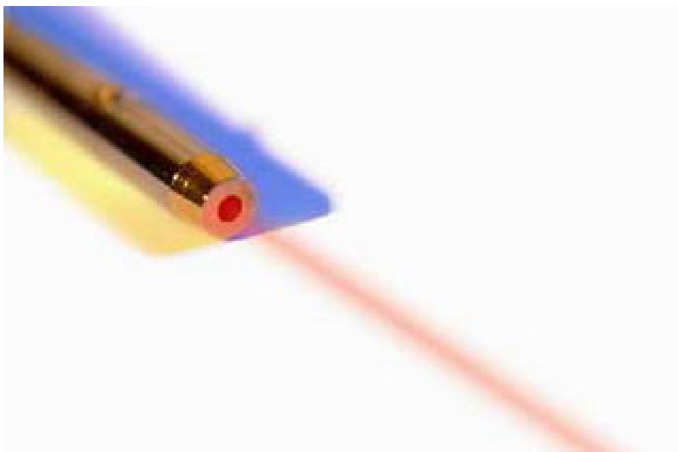

By synchronizing multiple lasers and then distributing them to different locations, scientists have found a way to build a quantum repeater. The method can extend the distance that information can travel in quantum computers using entangling swapping, where particles can become entangled without ever interacting due to a “go-between” particle.

As if plain old quantum entanglement weren’t strange enough for modern physics, now physicists are entangling already entangled particles. In entanglement swapping, one particle of an entangled pair becomes entangled with a third particle, which itself becomes entangled with the other particle in the first pair, even though the two never interact. Here’s how physicists are unraveling this behavior and manipulating it for use in quantum communications and high-speed computing.

Even as today's most powerful supercomputers can send information at ever increasing speeds, scientists predict that quantum computers will operate millions of times faster. With the help of entangled photons, which instantaneously correlate with one another even when separated by large distances, scientists are developing a process called quantum teleportation. Currently, however, physicists can only teleport information a hundred or so miles before signal loss weakens the connection.

One way to tackle the problem of signal loss is to place quantum repeaters along the quantum channel, where information is transferred when a photon belonging to an entangled pair can "swap" – or hand off – its entangled partner to another particle nearby, and so on down the channel. The doubly mysterious part of entanglement swapping is that the entangling photons never interact; in normal entanglement, particles must interact and then separate before demonstrating correlative behavior. Any kind of entanglement violates local realism, the theory that information should only be exchanged by particle interactions in a system's immediate surroundings.

For the first time, physicists Tao Yang, et al. in China have generated photon pairs created from entanglement swapping using multiple, completely independent entangled photon sources (previous experiments used a single photon source, which doesn't fully confirm non-interaction). In their study from a recent *Physical Review Letters*, the team designed an experiment to show that the entangled photons sharing information across a channel truly never interact.

"It's very hard to understand how information travels 'through' entangled particles, even for physicists," team member Jian-Wei Pan told *PhysOrg.com*. "But this did happen in the experiments. We believe that the information travels via two channels: the quantum entanglement correlation, and the classical channel. So the information cannot transfer beyond the speed of light."

The key to developing quantum repeaters that achieve entanglement swapping is to build photon sources that are at once perfectly synchronized and completely independent – a challenging experimental feat. To address the challenge, the physicists first synchronized pulses from two pump lasers near each other, and then placed the lasers at different segments in the channel.

The team synchronized the two lasers with a timing jitter of less than 2 femtoseconds (a millionth of a billionth of a second, or 10^{-15} seconds), and maintained that synchronization for more than 24 hours. This "perfect interference" of multiple photon sources enabled the physicists to violate a stipulation called "Bell's inequality," which places a limit on the strength of correlations between distant particles based on local realism. Part of Bell's inequality includes that distant particles cannot exchange information faster than the speed of light – while entanglement occurs instantly. Violation of Bell's inequality in this experiment allowed the physicists to generate and then swap entangled photon pairs, along with the information contained within them.

"With the synchronized multiple lasers and entangled photon sources, the distance of the quantum communications can be extended very efficiently," said Pan. "The total distance depends on the number of lasers used."

With a quantum repeater – containing an independent, synchronized photon source – located at periodic locations along the channel, a computational signal will receive a power boost, enabling it to continue toward its destination. In a sense, entanglement swapping is a bit like fueling your car at a gas station – but you can skip all the driving in between.

Citation: Yang, Tao, et al. Experimental Synchronization of Independent Entangled Photon Sources. *Physical Review Letters* 96, 110501 (2006)

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