Segment of a 'Quantum Repeater' Demonstrated

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Physicists at the California Institute of Technology have succeeded for the first time in the distribution of "entanglement" in a way that could lead to long-distance quantum communications, scalable quantum networks, and even a quantum internet.

In the April 5 online publication *Science Express*, Caltech Valentine Professor of Physics H. Jeff Kimble and his colleagues report that they have devised a crucial building-block of a "quantum repeater." The team has demonstrated a way to create a segment of a channel that can distribute quantum entanglement over distances. The division into segments and storage of entanglement in material systems is necessary for long-distance quantum communications to take place.

"This work provides a first primitive version of a quantum repeater segment," says Julien Laurat, a postdoctoral scholar in physics and one of the authors of the paper. "It opens an avenue for further investigations into this promising and new quest of large-scale networks where the currency of the realm is no longer classical information but rather quantum information."

Entanglement, one of the most striking features of quantum mechanics, leads to strong correlations between the various components of a physical system, regardless of the distance separating them. Entanglement's distribution enables quantum protocols, such as quantum cryptography where the security is guaranteed by the law of physics or quantum teleportation where a quantum state is faithfully transferred from one place to another.

"Physicists for some time have understood that the entanglement of quantum states could be exploited for various advances that are impossible with devices that operate according to the laws of classical physics," says Chin-Wen Chou, a former doctoral student of Kimble's and the lead author of the paper.

However, entanglement as a resource is fragile, and achieving such protocols over very long-distance is a challenge for quantum physicists. To achieve in a reasonable time long-distance quantum communications, namely the distribution of entanglement over such a distance, the channel has to be divided into many segments and entanglement generated and stored into material systems before connecting all them together. The Caltech group achievement is demonstrating an initial version of one of these segments.

The experiment involves two quantum nodes separated by 3 meters, each formed by two atomic ensembles separated by 1mm. The ensembles are clouds of about 100,000 cooled cesium atoms. With real-time control of the quantum states, entanglement is generated, stored into the atoms, which play the role of a quantum memory, and finally converted to photons on demand. This entanglement is stored in a heralded way, a critical requirement for scalability. In addition, the released entanglement is a so-called "polarization entanglement," an appropriate form for quantum communication applications.

"We demonstrated the capability to distribute entanglement between two locations in a form suitable both for quantum network architectures and for entanglement-based quantum communication schemes," says Kimble.

"The import of our experiment goes well beyond quantum communication protocols," Laurat explains. "It incorporates many complex procedures, confirming the more and more efficient control we can have in our labs to address in a coherent way the quantum states of atoms and light, and their interface."

The new work reported by Chou, Laurat, Kimble, and their coworkers is a significant leap towards quantum networking. However, the researchers also emphasize that "the extension of their work to longer chains involving many segments becomes more complicated, and still out of reach of any current system. A fully functional quantum repeater is still a challenging task, and its future achievement will be rich in fruitful discoveries."

This demonstration builds upon previous advances in the Caltech Quantum Optics Group in recent years, including the first demonstration of unconditional quantum teleportation and the initial demonstration of entanglement between two remote atomic ensembles, a crucial ingredient for the breakthrough reported here.

The title of the paper is "Functional Quantum Nodes for Entanglement Distribution over Scalable Quantum Networks." It is available on the *Science Express* website.

The other authors are Hui Deng, a postdoctoral scholar in physics; Kyung Soo Choi, a graduate student, and Hugues de Riedmatten and Daniel Felinto, both previous postdoctoral scholars at Caltech.

Source: California Institute of Technology