World's record entanglement storage sets up a milestone for Quantum Internet Alliance

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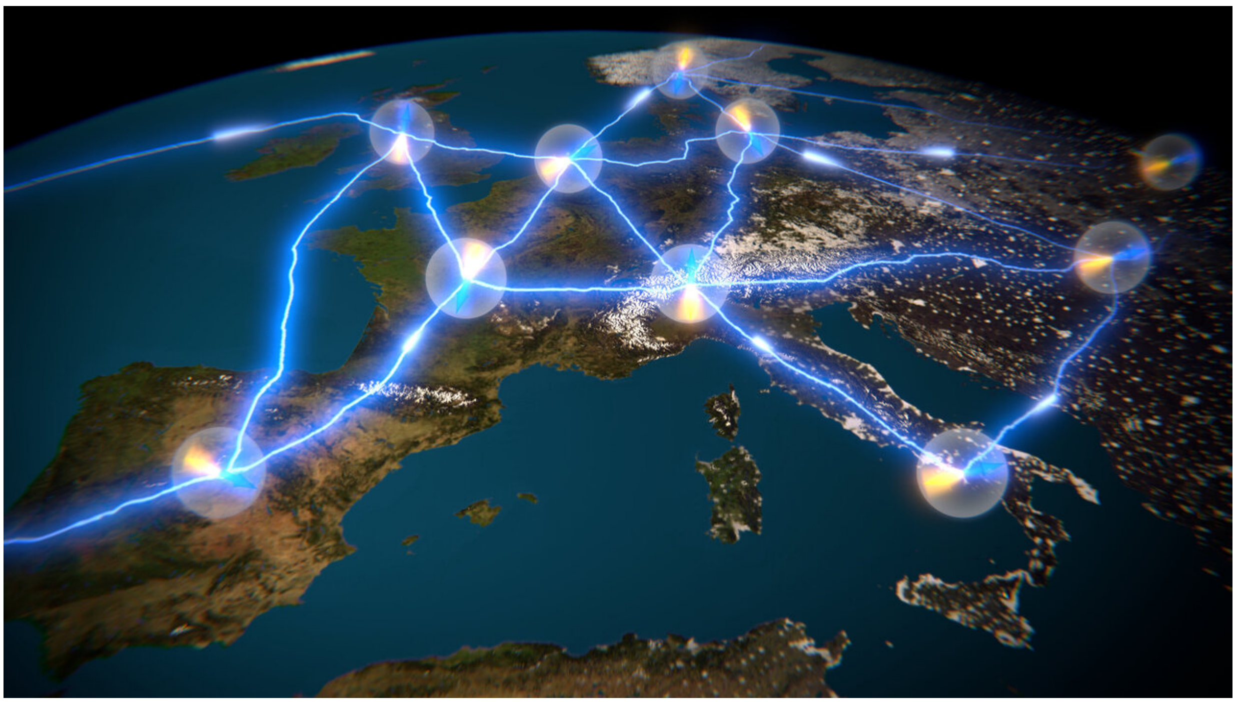


The Quantum Internet Alliance consortium is part of the first phase of funding of the EU quantum flagship. Credit: QuTech-Delft

Researchers from Sorbonne University in Paris have achieved a highly efficient transfer of quantum entanglement into and out of two quantum memory devices. This achievement brings a key ingredient for the scalability of a future quantum internet.

A quantum internet that connects multiple locations is a key step in quantum technology roadmaps worldwide. In this context, the European Quantum Flagship Programme launched the Quantum Internet Alliance in 2018. This consortium coordinated by Stephanie Wehner (QuTech-Delft) consists of 12 leading research groups at universities from eight European countries, in close cooperation with over 20 companies and institutes. They combined their resources and areas of expertise to develop a blueprint for a future quantum internet and the required technologies.

A quantum internet uses an intriguing quantum phenomenon to connect different nodes in a network together. In a normal network connection, nodes exchange information by sending electrons or photons back and forth, making them vulnerable to eavesdropping. In a quantum network, the nodes are connected by entanglement, Einstein's famous "spooky action at a distance." These non-classical correlations at large distances would allow not only secure communications beyond direct transmission but also distributed quantum computing or enhanced sensing.

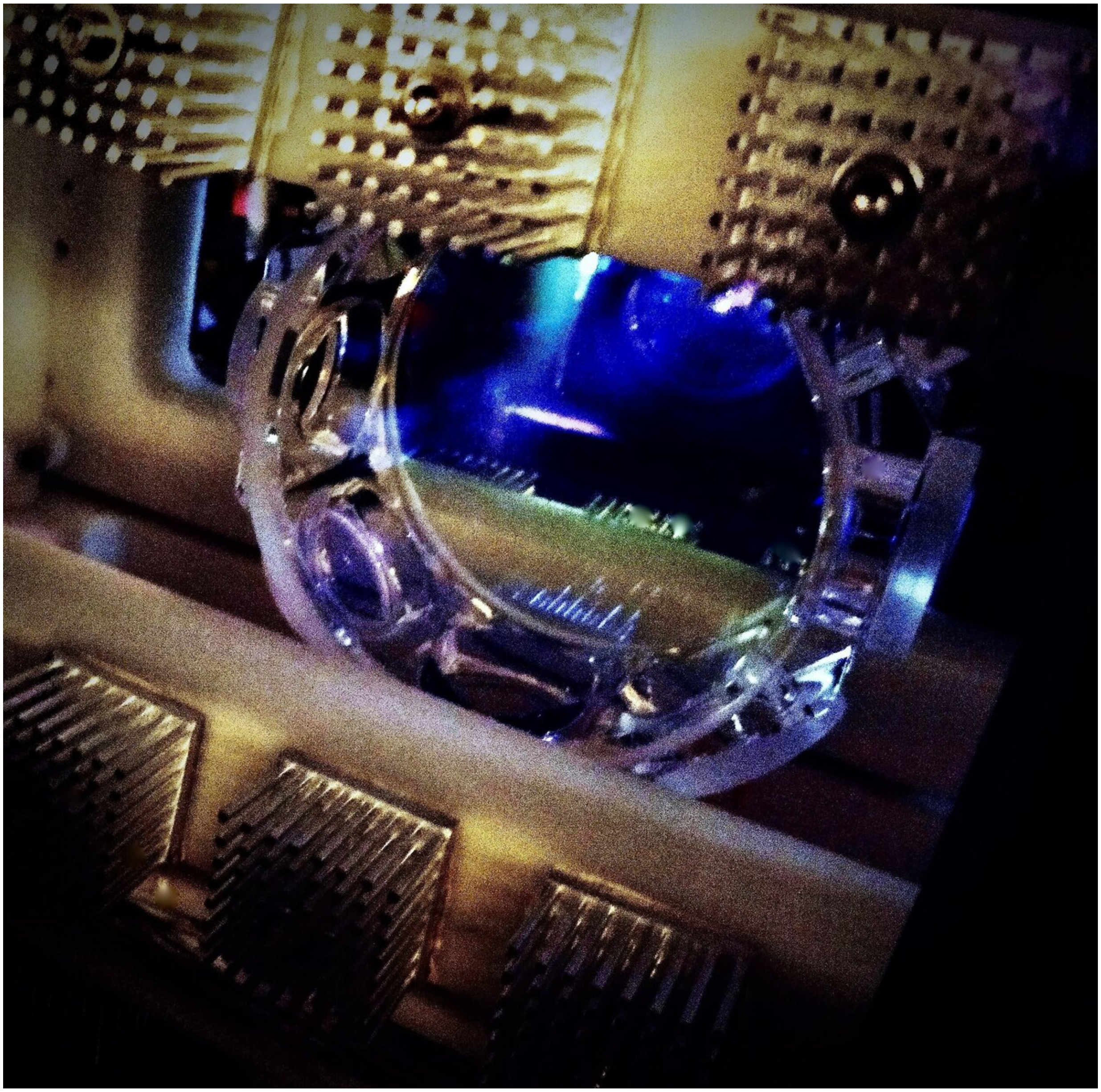
However, one major challenge in building large-scale quantum networks is the ability to generate such correlations between distant nodes. In principle, this challenge can be overcome if entanglement is reliably stored in quantum memory devices. By splitting the long distance into several shorter segments, it is possible to create entanglement between the ends of these elementary links, and then connect them until both initial nodes are entangled. The quantum memory devices store the entanglement, ensuring that entanglement has been created over all the segments before performing the connections. This protocol is known as a quantum repeater.

A critical parameter is the efficiency of the quantum memory devices: If one device fails in recording or retrieving the entangled light, the quantum repeater cannot function properly. For instance, an increase in storage-and-retrieval efficiency from 60% to 90% drastically decreases the average time for entanglement distribution over a distance of 600 kilometers, typically by two orders of magnitude. One of the goals of the QIA consortium is to lay the groundwork for quantum repeater technology by building highly efficient memory devices for entanglement using different physical platforms.

In the October 2020 online issue of *Optica*, Prof. Julien Laurat and his team at Kastler Brossel Laboratory (Sorbonne Université, CNRS, ENS-Université PSL, Collège de France) reported a long-awaited step for this endeavor. They have demonstrated the storage and retrieval of entangled light beams into two quantum memory devices, with an overall efficiency as high as 85%. This value constitutes more than a three-fold increase relative to prior works in the field.

"This achievement is the result of 10 years of experimental developments in our lab. It now opens the path to further investigation as many potential network architectures assume such efficiency value for scalability," says Félix Hoffet, a Ph.D. student at LKB and one of the leading authors of the paper.

The Paris experiment involved a very elongated ensemble of laser-cooled cesium atoms and was based on the protocol called electromagnetically induced transparency. A control laser beam makes the medium transparent and slows down the impinging signal light carrying the information. When the signal is contained within the ensemble and the control beam is turned off, the information is converted into a collective excitation of the atoms, which is stored until the control beams is turned on again. Laurat's team first generated two light beams that are entangled and then mapped them into two memories following this protocol. By using specific atomic transitions and reaching a very large absorption in each memory, the researchers were able to write and read out the entanglement with unprecedented efficiency, while preserving a very low noise contamination.



A 3 cm-long ensemble of cesium atoms laser-cooled in a glass chamber is used as a quantum memory. Credit: LKB

"Our record efficiency first required a strong theoretical effort to understand better the limiting factors in our prior implementation and then an experimental tour-de-force to combine all the required ingredients together," adds Mingtao Cao, a former Marie Curie postdoctoral fellow and the other leading author of the paper. Alexandra Sheremet, a former Marie Curie Fellow and also an author of the paper, played a key role in simulating the whole process and taking into account the complexity of multiple energy levels in this atomic system.

The work reported in *Optica* is a stepping stone for further investigations. However, the path for building large-scale networks is still paved with challenges. For example, efficient quantum memory devices also need to have long storage times in order to create entanglement faster than it is lost. This critical feature can also come with the ability to store different information in parallel. The QIA consortium is tackling these various aspects, both theoretically and experimentally. Prof. Laurat's team in Paris is focusing for instance on the development of "spatially multiplexed" memories that can store several states at the same time in order to parallelize quantum connections.

More information: Mingtao Cao et al. Efficient reversible entanglement transfer between light and quantum memories, *Optica* (2020). DOI: 10.1364/OPTICA.400695

Provided by Sorbonne University

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