Exploring quantum network teleportation between non-neighboring nodes

Quantum teleportation allows for the transfer of quantum information across a quantum network without any loss. In a recent article published in *Nature* (https://doi.org/10.1038/s41586-022-04697-y), researchers have shown teleportation between indirectly connected nodes. Introducing the network element to the teleportation protocol shows it to be a key ingredient for distributing quantum states among multiple quantum computers and therefore enhancing their computational power. How is this all possible? Answer: by establishing an entangled link to teleport quantum information.

In this story, three essential players make this possible: Alice, Bob, and Charlie—this trio makes up the quantum network. Each node hosts a nitrogen-vacancy center in a diamond chip; its electronic spin operates as a communication qubit. Upon laser excitation and subsequent overlapping of the photon emission, remote entanglement between each pair of neighboring nodes can be generated. When Bob shares an entangled state with Alice and Charlie, he can connect Alice and Charlie via “entanglement swapping”; he swaps his part of the entangled state with Alice to Charlie. This establishes the teleporter. Now, Charlie can prepare the quantum state he wishes to teleport and subsequently perform a so-called Bell measurement to perform the actual teleportation. Depending on the outcomes of this measurement, Alice performs an operation and, voilà, Alice obtains the quantum state.

“For the first time, on this rudimentary quantum network, we were able to teleport information between nodes that are not directly connected, showing that the teleportation protocol is a key protocol to transfer information in a loss-less manner, also in larger networks,” says Sophie Hermans, the lead researcher for this endeavor from the QuTech and Kavli Institute of Nanoscience at Delft University of Technology.

However, the beauty of the discovery is not without challenges. The rate at which the teleporter, the entangled state between Alice–Charlie, is being generated poses a big challenge. It takes roughly two minutes to prepare the teleporter successfully and teleport one quantum bit of information, caused by the entanglement rate of the neighboring nodes in combination with the storage with quantum states. After a specific time of network activity, the quantum information stored on a memory qubit was completely destroyed. The network activity caused errors and decohered the quantum information stored on the memory qubit. To overcome this challenge, follow-up research focused on different defects in the diamonds as well as diamond chips in microscopic optical cavities. Embedding an optical emitter on an optical cavity leads to a higher collection efficiency of the emitted photons and under certain requirements to a higher emission rate. Hence, both routes promise more photons available for remote entanglement generation and consequently higher entanglement rates.

Another consequence of the limited teleportation rate is the time it took for the research team to collect data to prove the success of the experiment in a statistically significant manner. For roughly three weeks, the researchers supervised the experiment almost 24/7, which is demanding for any devoted team. For future and more extensive networks, the operation of the nodes would ideally involve no human supervision.

In addition, future research will focus on the integration of the hardware (experimental apparatus) with a Quantum Internet stack. In such a stack, different software control layers will have different responsibilities, for example, routing entanglement between far ends of the network, using multiple nodes in the middle. By dividing the responsibilities, more abstract control would allow a larger range of people to program and make use of it, not just quantum physicists. The larger picture here is higher connectivity rates, more automation, and more abstract control.

“Once the research moves beyond rudimentary networks, with a mature Quantum Internet stack, it can be used to teleport data securely and reliably for all sorts of applications,” Hermans says.

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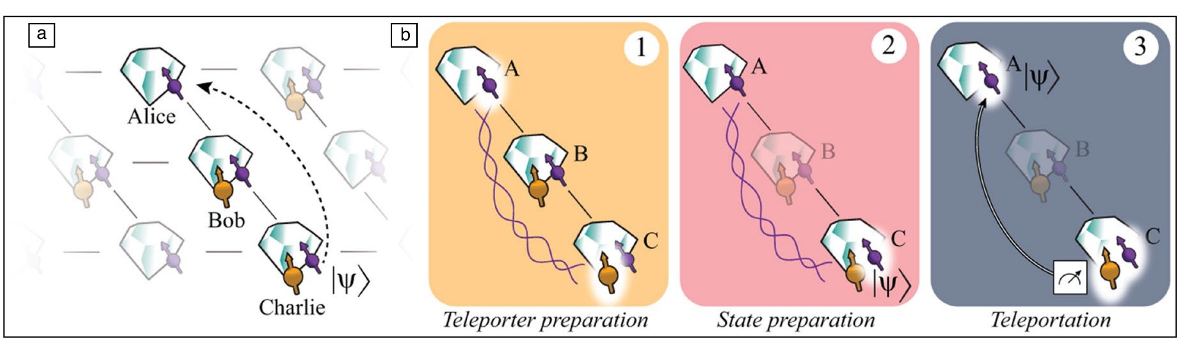

(a) The trio network consists of Alice, Bob, and Charlie. In the experiment, Charlie teleports a quantum state to Alice. (b) The three phases of the teleportation protocol. First, the teleporter between Alice and Charlie is made with the help of Bob. Second, Charlie prepares the state to teleport. Third, the teleportation is executed by Charlie, and Alice can reconstruct the quantum state. Credit: *Nature*.