Quantum information

Teleportation beyond network neighbours

Oliver Slattery & Yong-Su Kim

Innovations have been developed that facilitate quantum teleportation between nodes in a quantum network that do not neighbour each other, paving the way for complex network configurations. See p.663

In the quantum communications networks of the future, stationary quantum bits (qubits) made from atoms, ions and various other types of matter will form network nodes for applications such as quantum computing. The remarkable process of teleportation will be used to send quantum information between these stationary qubit nodes. A major challenge for researchers and developers is how to implement teleportation across the network as it grows and becomes more complex. On page 663, Hermans *et al.*[1] report a demonstration of quantum teleportation between stationary qubit nodes that are not directly connected by a quantum channel – a key step towards reaching far-flung nodes and so fully harnessing the power of a quantum internet[2,3].

The principle of quantum teleportation is based on the fact that the quantum state of two qubits can be entangled, such that an action (for example, a measurement) on either of the qubits will play out on both qubits, even when they are physically separated. This entanglement acts as a resource for the teleportation process: the sender and receiver share a pair of entangled qubits; the sender then performs a measurement called a Bell-state measurement on the information qubit they wish to teleport and their entangled qubit; and this measurement affects the receiver's entangled qubit such that a simple operation on it will recover the sender's information qubit[4] (Fig. 1). The only information that is physically sent to the receiver is the operation that is to be performed on the receiver's qubit. This operation is determined by the random result of the Bell-state measurement, and it carries no information about the teleported quantum state.

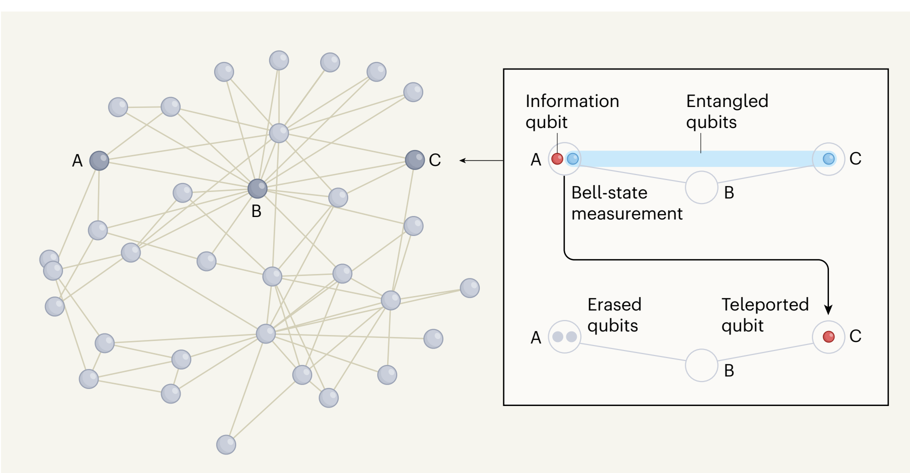

Figure 1 | Quantum teleportation between unconnected network nodes. Hermans *et al.*[1] demonstrated quantum teleportation between unconnected stationary quantum bits (qubits) in a quantum network comprising three nodes – Alice (A), Bob (B) and Charlie (C) – that had direct links between Alice and Bob, and between Bob and Charlie, but not between Alice and Charlie. Quantum teleportation involves a sender and receiver sharing a pair of entangled qubits, such that the quantum state of each qubit depends on that of the other. A type of measurement called a Bell-state measurement is then performed on one of the entangled qubits and on a qubit containing the information to be teleported. This measurement affects the receiver's entangled qubit, such that a simple operation allows the receiver to recover the sender's information, which is erased from the sender's qubits. Hermans *et al.* used separate entangled links to Bob to swap the entanglement to Alice's and Charlie's qubits without the two being directly connected. A groundbreaking series of steps (not shown) ensured that the fidelity of the entanglement was high enough to achieve quantum teleportation from Alice to Charlie.

Quantum teleportation was first demonstrated 25 years ago using photons[5], which have since been shown to be capable of teleporting quantum information through satellite and metropolitan fibre networks[6,7]. Following substantial advances in materials science, quantum information was successfully teleported between matter-based stationary qubits[8]. However, because of the demanding requirements for high-fidelity entanglement and efficient light–matter interfacing, quantum teleportation between stationary qubits was possible only when the qubits were connected by a direct quantum channel – until now. With a series of innovations, Hermans *et al.* have taken things a step further by meeting those requirements and demonstrating quantum teleportation using stationary qubits that are not directly connected.

The authors used diamond-based stationary qubits placed at three nodes in a quantum network. Such nodes are typically labelled Alice, Bob and Charlie in quantum communications, and, in this case, the network included a direct link between Alice and Bob, a direct link between Bob and Charlie, but no such link between Alice and Charlie (Fig. 1). Hermans *et al.* initially established high-quality entanglement between the neighbouring nodes (between Alice and Bob and between Bob and Charlie). They then undertook an 'entanglement swapping' process in which Bob's intermediate node facilitates the entanglement of quantum states at the two non-neighbouring nodes of Alice and Charlie. But the authors' innovation was in implementing a series of steps to mitigate infidelity in the process so as to ensure that the final shared entangled state between Alice and Charlie is of sufficiently high quality to achieve quantum teleportation.

To create a reliable entanglement link between Alice and Charlie, both of these initial connections must be prepared in time for the entanglement-swapping operation. Hermans *et al.* achieved this by protecting the link between Alice and Bob in a quantum memory qubit while the link between Bob and Charlie was being formed. This protection essentially shields the memory in a magnetic field, providing enough time for many attempts to complete both links. In comparison with previous efforts by the same group[9], this advance doubled the formation rate of entanglement links that were of sufficient quality for teleportation.

An essential process in multiple stages of Hermans and co-workers' teleportation protocol is the exchange of qubits between memory and photons (called an optical interface). The researchers used several novel measures to retain readouts from the quantum memory that had a high probability of being reliable, while efficiently discarding readouts that were deemed less consistent. Using this strategy, they achieved a sixfold decrease in the average infidelity of the process.

Combining these innovations, Hermans *et al.* succeeded in teleporting quantum information between Alice and Charlie — two nodes without a direct connection. This achievement is not only a win for fundamental science, but also represents an advance in the real-world problem solving required to move this fascinating quantum application to the next step. Reliable teleportation around a quantum network remains some way off, and this work makes clear the massive challenge ahead for true realization of the quantum internet — but Hermans *et al.* offer a potential path forward. Increasing the robustness of the memories used to preserve entanglement will lead to even higher entanglement rates, and an improved optical interface will boost the efficiency with which remote nodes are entangled. This, the authors say, will be crucial for scaling the advances in this work to ever-more-complex quantum network configurations.

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Neuroscience

Volatile neurons unite to stabilize visual experience

Tatiana A. Engel

It has been unclear how the brain creates stable visual experiences from the highly variable activity of individual neurons. Imaging from thousands of neurons across the entire mouse visual cortex provides an explanation. **See p.713**

Our senses provide us with a stable experience of the surrounding world. Whether you look at the family photo on your desk now, in an hour or next week, you'll still see the same image. This perceptual stability is astonishing, given how variable neural activity is in the brain's visual cortex. Single neurons respond with different strengths every time we look at the same image. Moreover, neurons change their sensitivity across days — so a neuron that reliably responds to an image today might be unresponsive tomorrow. On page 713, Ebrahimi *et al.*[1] provide an explanation for this apparent contradiction.

The authors performed a first-of-a-kind experiment, simultaneously recording the activity from thousands of neurons scattered across the entire visual cortex, in mice performing an active visual task. They obtained recordings on this extraordinary scale by using advanced microscopy techniques and proteins called genetically encoded calcium indicators (GECIs). GECIs provide a pulse of fluorescence when a neuron is active and — under the right microscope — reveal the activity of thousands of individual neurons at once. The researchers tracked the activity of the same neurons as the mice performed the task multiple times over five to seven days.

The animals had to discriminate between two visual stimuli on a screen. One cued them to lick a spout for a water reward; the other indicated that they should not lick. Ebrahimi and colleagues measured how reliably the activity of cortical neurons differentiated between the two stimuli and how stable this activity was over time. They also linked neural activity patterns to the animals' perception of the stimuli — assessed by whether the

> **"This result provides an elegant explanation for how long-term, invariant stimulus decoding is possible in a population of volatile neurons."**

From the archive

A laboratory for studying coral reefs opens in Jamaica, and the diverse uses for photography.

50 years ago

Coral reefs are the most complex of marine ecosystems. Their investigation has been held back by lack of adequately equipped laboratories from which ... long term observations ... can be conducted and where physiological work can be carried out in the closest contact with ecological studies. An important advance in the filling of such a need was made with the opening ... of the Discovery Bay Laboratory on the north coast of Jamaica ... It is expected that the laboratory will soon become a leading centre for research in tropical marine biology.

From *Nature* 26 May 1972

150 years ago

The applications made of photography now-a-days are as various as they are numerous. Irrespective of the ordinary every-day uses to which the art is put in reproducing scenes and objects, or pandering to human vanity ... [t]o the chemist, the surgeon, the engineer, and others, its aid is frequently of considerable importance, while to the astronomer and physicist the assistance it renders is at times indispensable ... In the study of medicine, ... photography lends a helping hand, so firm and true that we are at once guided to our destination ... And perhaps while treating on this particular subject, we may be allowed to refer also to the use made of the micro-camera during the siege of Paris for conveying news from and to that city. We have all heard how batches of private letters and whole sheets of newspapers have been reduced by means of photography to within the most insignificant limits, and produced upon a transparent pellicle, of which a pigeon might without inconvenience carry several under its tail, and how these precious films, on arrival at their destination, were forthwith placed in an enlarging apparatus or under a microscope, to be amplified to their original dimensions.

From *Nature* 23 May 1872