Quantum communication without entanglement could perform faster than previously thought possible

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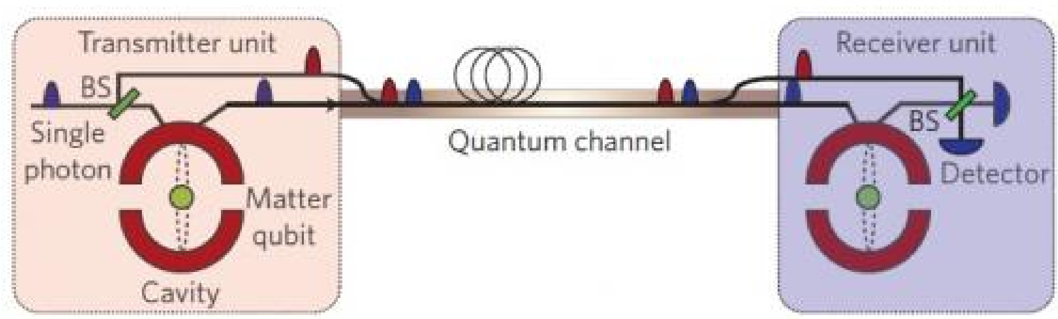

Illustration of the new quantum communication scheme, where information is directly transmitted from one node to another using a transmitter unit and a receiver unit. The scientists calculated that the new approach could potentially enable communication rates several orders of magnitude faster than other approaches. Credit: W. J. Munro, et al. ©2012 Macmillan Publishers Limited

In order to build a quantum internet – a network that is faster and more secure than the current internet – the key is the ability to transmit quantum information between remote quantum computers (i.e., nodes). The most familiar approach involves entangling the links between nodes and then using quantum repeaters at intermediate locations to provide entanglement swapping, extending the range of entanglement across km-long networks.

In such a system, the performance is inherently limited by the time it takes to establish entanglement between nodes. This time is at best the classical signaling time between the nodes, but with many schemes it is even longer, and increases as network size increases. Since the qubits that store the quantum information are unstable and quickly decohere, quantum memories are required to store quantum information for milliseconds or longer while they wait for entanglement. The result is a theoretical limitation on speed due to the system's design and the need for additional components – quantum memories – to enable a functioning network.

In a new study published in Nature Photonics, scientists from Japan and the UK have presented an alternative design for a quantum communication network that requires neither entanglement between nodes nor quantum memories. Instead, the scheme transmits quantum information in encoded form directly across the network, using devices that act as quantum repeaters (without entanglement) to transmit and receive information between each other. Because this approach doesn't use entanglement, the communications rate is not limited by the conventional restraints that limit the rates of entanglement-based approaches.

"The significance of this work is that we have removed the need for classical messages to herald the generation of entanglement between adjacent nodes," coauthor Bill Munro of NTT Basic Research Laboratories in Kanagawa, Japan, and the National Institute of Informatics in Tokyo, Japan, told *Phys.org*. "This classical signal means our qubits at the remote nodes had to wait until it could be found out whether they were entangled or not. With repeater nodes separated by tens of kilometers, this waiting time was on the order of hundreds of microseconds. This means we needed long-lived quantum memories (milliseconds or longer life times) to store the information (entanglement) that was in those qubits.

"Our new scheme removes the need for long-lived quantum memories, as we do not aim to establish entanglement between the remote nodes. Instead we send an encoded signal between the nodes. Once the message has left one node to be transmitted to the next node, the resources available in the first node are freed up and the next message can be sent down the channel (even before the second node has received the first message), thus increasing the rate at which information can be transmitted. Entanglement-based approaches cannot do this, so their only route to higher communication rates is by paralleling resources within the node."

In the new approach, information is stored in matter qubits, such as electron spins, in the transmitter and receiver units. The transmitter, which contains a single-photon source, transfers the information from the matter qubits to the photonic qubits. Then it sends the photonic qubits down an optical fiber to the receiver, which contains a single-photon detector. The receiver operates in reverse, transferring the information from the photonic qubits back to matter qubits.

Unlike traditional schemes, the new scheme doesn't require entanglement between the matter qubits at the two remote nodes. As soon as the transmitter moves the information from the matter qubit to the photonic qubit, the matter qubit is no longer needed, so quantum memory is not required to store its information.

After the completion of one cycle, the final matter qubit is checked for errors using a redundant quantum parity code. Since channel losses and source/detector inefficiencies are inevitable, quantum states can easily be degraded during quantum communication. The error correction code protects against this degradation by measuring the states of several matter qubits that all carry the same information. The physicists showed that this encoding process can tolerate photon loss in excess of 50% in the quantum channel between nodes, which allows for nodes to be spaced further apart than usually thought.

After the error correction code verifies successful transmission of a qubit, the receiver then acts as a transmitter and sends the information on to the next node in the network. The scientists calculated that the scheme could transmit data at a rate of 10^7 quantum states per second, and operate over a distance of at least 17 km between nodes. With 48 nodes, quantum information could be transmitted over 800 km with a success probability of greater than 98%. The scientists calculated that the new approach could potentially enable communication rates several orders of magnitude faster than other approaches. In addition to speed, the new scheme also has other routing advantages.

"Our solution also makes it very easy to see how one can send information on a more complicated quantum network," Munro said. "Each node would have a telephone-like number and then we can think of telephone-like exchanges that route the information to where it needs to go. The node that sends the original message does not need to know the route to the final destination. Instead it just needs to get to a local exchange which can route it through the chain using country, region, and city parts of the telephone-like number."

In the future, the researchers plan to tackle some of the technical challenges facing the new quantum communication scheme.

"Our future plans are an experimental implementation of this approach," Munro said. "Currently we are working on ways to improve our local gates within our physical system – a necessary step to showing our new communication scheme.

"The key requirement in this new approach is the need for efficient quantum gates within the repeater node," he added. "In the normal entanglement-based approach, we can work with gates that fail a lot of the time in a heralded way. Currently, efficient quantum gates are experimentally challenging to achieve but they need to be achieved if distributed quantum computers are going to be achieved."

More information: W. J. Munro, et al. "Quantum communication without the necessity of quantum memories." *Nature Photonics* DOI: 10.1038/NPHOTON.2012.243