First Proof-of-principle Experiment of Quantum Repeaters with All Photonics—Major Step towards a Quantum Internet as the Holy Grail of Information-processing Networks

1. Summary

A research team consisting of Prof. Takashi Yamamoto and Assistant Prof. Rikizo Ikuta at Osaka University and a research team consisting of Dr. Koji Azuma at NTT, collaborating with Emeritus Prof. Nobuyuki Imoto at Osaka University, Prof. Kiyoshi Tamaki at the University of Toyama and Prof. Hoi-Kwong Lo at the University of Toronto, have succeeded in demonstrating a first proof-of-principle experiment of quantum repeaters by adopting an all-photonic quantum repeater protocol. This protocol enables a global quantum network using only optical devices (**Fig. 1**).

2. Background

The current Internet is based on a global optical fiber network, where long-distance communication is enabled by repeaters. An all-optical-network approach involves using only communication devices made with optical components. This approach holds promise for an energy-efficient high-speed Internet.

The quantum version of this all-optical approach is called an all-optical quantum network and can be realized by replacing the conventional repeaters with all-photonic quantum repeaters. This would lead to a future *quantum internet*[*1] that would have applications far beyond the current Internet.

The all-photonic quantum repeater protocol was proposed in 2015 [1, 2] as a promising quantum repeater protocol that is implementable only with optical devices, in contrast to conventional schemes necessitating matter quantum memories.[*2] However, since the all-photonic protocol is based on a new principle called time-reversal that is enabled only with quantum entanglement,[*3] demonstrating this principle experimentally is regarded as the first major step towards realizing not only all-photonic quantum repeaters but also the quantum internet.

3. Research results

Prof. Yamamoto's group at Osaka University, in collaboration with NTT, the University of Toyama, and the University of Toronto, has successfully demonstrated experimentally a key component of all-photonic quantum repeaters—the time reversal. This corresponds to a first proof-of-principle experiment of all-photonic quantum repeaters.

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*1 Quantum internet: In the field of quantum information, a quantum internet describes a global quantum-communication network that enables the exchange of quantum information—which is represented by quantum superposition states—between arbitrary information-processing devices all over the world.

*2 Matter quantum memory: Quantum memory is the function to store the quantum superposition states for a certain period of time. For instance, in contrast to the memory in conventional computers that can store both bit values 0 and 1, quantum memory can store not only 0 and 1 but also their quantum superposition states. A matter quantum memory is the realization of quantum memories based on matter such as an atomic ensemble, a single atom, an ion trap, a quantum dot, a superconducting qubit, and a nitrogen-vacancy center in a diamond.

*3 Quantum entanglement: A quantum superposition state of composite systems that can never be expressed by any collection of the descriptions of the subsystems. This is an essential resource for quantum communication and quantum computation. The existence has already been experimentally demonstrated by using photons and atoms.

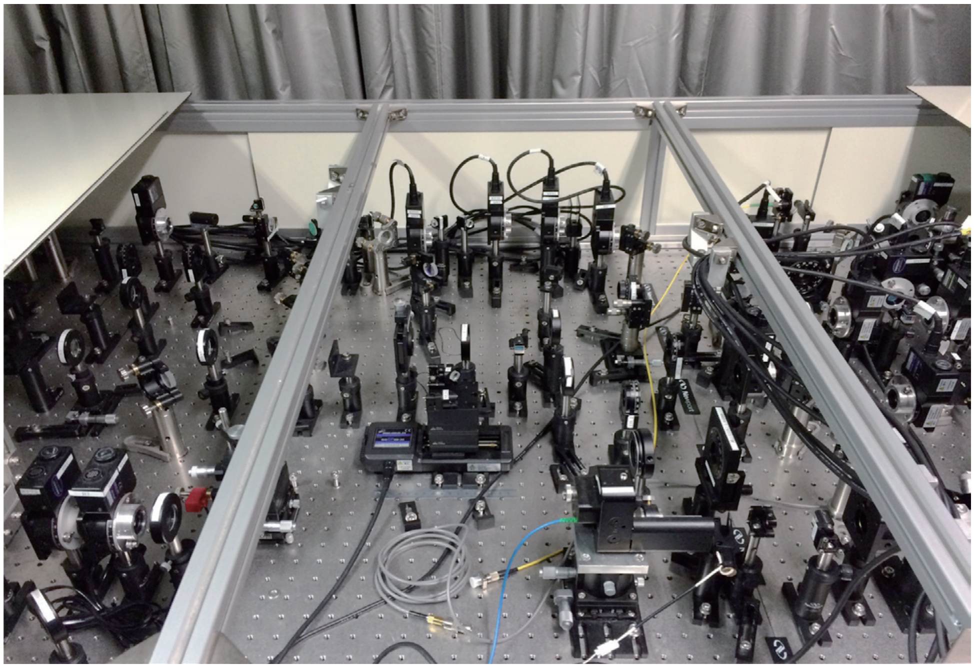

Fig. 1. Experimental setup for all-photonic quantum repeaters.

This demonstration indicates that not only all-photonic quantum repeaters but also a global all-photonic quantum internet is possible once ultralow-loss integrated optics and efficient entanglement light sources are available. At the same time, the current demonstration also corresponds to a first proof-of-principle experiment of an adaptive Bell measurement,*4 which is required for arbitrary quantum repeater schemes (including the conventional approach with matter quantum memories). This suggests that the all-optical approach is one-step closer to achieving quantum repeaters than conventional approaches.

4. Future prospects

This experiment showed that the all-photonic repeater approach has a promising advantage compared to the other approaches with matter quantum memories for building a worldwide quantum internet. The next steps towards achieving the quantum internet with the all-photonic repeaters are developing large-scale graph-state photon generators and ultralow-loss photonic circuits so as to be able to perform a larger-scale adaptive Bell measurement. This experiment is merely a first step. However, it is essential for achieving a future energy-efficient high-speed quantum internet, where we are able to enjoy absolutely secure communication, uncopiable money, secure e-commerce, longer-baseline telescope arrays, a single international clock with high stability and accuracy, cloud quantum computing, large-scale quantum computer networks, and other benefits.

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*4 Adaptive Bell measurement: The Bell measurement is a measurement on a pair of particles to reveal which state of possibly maximally entangled states has been taken by the pair of particles. Each quantum repeater needs to perform the Bell measurement on a pair of particles, on confirming that each particle shares quantum entanglement with other repeater nodes. This Bell measurement performed in an adaptive manner is called adaptive Bell measurement.

References

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