Quantum Network: quantum communication, computation, and metrology

Jian-wei Pan

University of Science and Technology of China, Jinzhai Road 96, Hefei, China

With the continued development of quantum information science, it is anticipated that large-scale quantum networks will be established. Such networks are expected to enable ultra-precise information sensing through quantum metrology, secure and efficient information exchange via quantum key distribution (QKD) and quantum teleportation, and rapid information processing through quantum computing.

However, turning quantum networks from theoretical concepts into practical reality still faces numerous technical challenges. Achieving secure long-distance quantum communication requires addressing security issues under realistic conditions and overcoming the inherent loss in optical fibers, while building quantum computers demands solving the challenge of scalable and precise manipulation of qubits.

In this talk, I review our two-decade efforts toward quantum networks, including: developing decoy-state QKD and measurement-device-independent (MDI) QKD to close device imperfections loopholes; progressing quantum repeaters and satellites to extend communication range; using photon coherent manipulation techniques developed from quantum communication to demonstrate quantum computational advantage; employing ultracold atoms in optical lattices for quantum simulations of complex systems, advancing near-term quantum computing applications; surpassing the surface code quantum error correction threshold; and developing high-precision optical lattice clocks using ultracold atom technology.

Future prospects include building a global quantum communication network using efficient constellations and geostationary orbit (GEO) satellites. This will also support advanced quantum metrology, potentially redefining the SI second. In quantum computation, our five-year plan targets practical quantum simulators to study high-temperature superconductivity, quantum Hall effect, etc. Over the next 10-15 years, scaling to millions of qubits with quantum error correction may lay the foundation for universal quantum computers.