

Summary of Progress in Quantum Teleportation

This paper provides a comprehensive review of the advancements in **quantum teleportation**, a cornerstone protocol in quantum information science, with a focus on developments since 2015. Quantum teleportation allows the transfer of an unknown quantum state from one location to another without the physical transmission of the particle itself. This process requires two channels: a **quantum channel** (via entanglement) and a **classical channel** (to communicate measurement outcomes).

Initially, quantum teleportation was a theoretical concept, but it has now evolved into a practical tool with significant implications for **quantum communication** and **quantum computing**.

Key Highlights

1. Theoretical Foundations:

- The protocol requires pre-shared quantum entanglement and classical communication to achieve state transfer.
- Recent work has clarified the **nonclassical nature** of teleportation, demonstrating that quantum entanglement enables fidelity beyond classical limits.
- Variants such as **port-based teleportation** and **quantum entanglement swapping** have broadened theoretical understanding and applications.

2. Experimental Developments:

- **Complex Quantum States:** Researchers have successfully teleported high-dimensional quantum states and multiple degrees of freedom (DoFs), such as polarization and orbital angular momentum. These advancements aim to encode more information in single photons, enhancing efficiency.
- **Long-Distance Teleportation:** Experiments have demonstrated teleportation over significant distances using:
 - **Metropolitan fiber networks:** Teleportation has been achieved across city-scale networks with high fidelity.
 - **Free-space satellite links:** Ground-to-satellite teleportation over 1,400 km has set records for long-distance quantum communication.
 - **Integrated photonic chips:** These enable compact and stable platforms for teleportation with potential for scalable quantum networks.

3. Applications:

- **Quantum Communication:**
 - Teleportation extends the reach of quantum networks by overcoming the distance limitations of direct transmission using **quantum repeaters**.
 - Satellite-based teleportation demonstrates feasibility for a global quantum internet.
- **Quantum Computing:**
 - **Gate teleportation** enables interaction between spatially separated qubits, forming the basis for distributed quantum computing.
 - Fault-tolerant quantum computing benefits from teleportation-based encoding and error correction.

Outlook

The paper identifies several challenges and opportunities:

- **Challenges:**

- Improving entanglement generation and Bell-state measurement (BSM) efficiency.
- Scaling quantum teleportation for practical, high-speed quantum networks.

- **Opportunities:**

- Advances in deterministic photon sources and nonlinear optics could enhance teleportation success rates.
- Hybrid systems combining photonic, atomic, and solid-state technologies promise robust quantum networks with diverse applications.

Overall, quantum teleportation is positioned as a vital technology for realizing the vision of a **quantum internet** and for enabling distributed, large-scale quantum computing.