Quantum Communication Technology: State of the Art and Challenges Ahead

Marco Lucamarini[1,2]

[1]*York Centre for Quantum Technologies, University of York, York, United Kingdom*
[2]*School of Physics, Engineering and Technologies, University of York, York, United Kingdom*

Quantum communication is transitioning from a fundamental research topic to an emerging technology capable of providing information security guaranteed by the laws of physics. Among its most mature applications, quantum key distribution (QKD) enables the generation of cryptographic keys with security independent of computational assumptions [1,2]. However, practical deployment remains limited by several challenges, including implementation security, transmission distance, and system integration.

This talk reviews the current state of quantum communication technologies, with a focus on fibre-based QKD systems. The central topic is recent advances in long-distance quantum communications, particularly Twin-Field (TF) QKD [3]. This protocol overcomes the repeaterless secret key capacity bound [4] and acts as an effective one-node quantum repeater. Since its proposal, TF-QKD has enabled secure key distribution over unprecedented distances and loss, exceeding 1000 km in optical fibre and 150 dB, respectively [5–7]. Key theoretical developments and experimental breakthroughs, including phase stabilisation techniques and field trials, are reviewed, including recent results and demonstrations from our group.

Complementary approaches to extending quantum communication networks are also discussed, including trusted-node architectures [8], satellite-based links [9], and emerging quantum repeater technologies [10,11]. Recent field demonstrations, including terrestrial and submarine fibre links, highlight both the feasibility of large-scale deployment and the remaining engineering challenges. These developments outline a path towards scalable quantum networks and the future quantum internet, where advances in fundamental physics, system engineering, and network architectures will play a crucial role in enabling next-generation secure communication infrastructures.

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