Long-Distance Quantum Key Distribution with Multicore Fiber

Quantum key distribution (QKD), a main application in quantum technology, allows the remote generation of a secret key between two parties.[1] Increasing the generation rate of these secret keys constitutes a major current challenge. One direct approach is to increase the overall efficiency in the use of the channel by expanding the dimensionality of the quantum information carriers (single photons). Traditionally, most quantum information experiments have used 2-D systems—so-called qubits. If we resort to an *N*-dimensional Hilbert space, we can increase the information-carrying capacity of a single photon to $\log_2 N$ bits.[2]

One way to expand the Hilbert space is to encode information onto the transverse momenta of single photons. Most such quantum communication experiments have been done in free space, because significant and unpredictable mode coupling happens even after short distances in optical fibers, thus preventing spatially encoded quantum systems from being recovered after their propagation.

Recently, in a step forward for experimental QKD, we performed the first QKD session over long optical fibers using path-encoded high-dimensional states.[3] Our experiment covered a record distance of 300 m in the telecom band—a huge leap relative to previous achievements with spatial quantum photonic states.[4]

The key idea is to employ path encoding over the *N* cores of a multicore fiber, thereby encoding an *N*-dimensional quantum state, or qudit. The fiber works like a multi-parallel-path conduit, providing excellent shielding from environmental phase drifts, since all cores are physically constructed in a common cladding. Because our approach is based on commercial multicore fibers, it offers direct compatibility with the fiber-based optical networks of the future.

In the experiment, we performed a BB84 QKD session using 4-D quantum states (ququarts), transmitted over a 300-m-long four-core fiber. We employed deformable mirrors for preparing and measuring the required states of the BB84 QKD protocol. The dynamically prepared states were coherently propagated through the fiber to the measurement station. The QKD session showed high stability, maintaining an overall quantum bit error rate of 10.25±0.6 percent over more than 20 hours of continuous operation. A decoy-state security analysis showed that our technique enables a positive secret key rate over metropolitan distances, opening up many possibilities in quantum information processing. OPN

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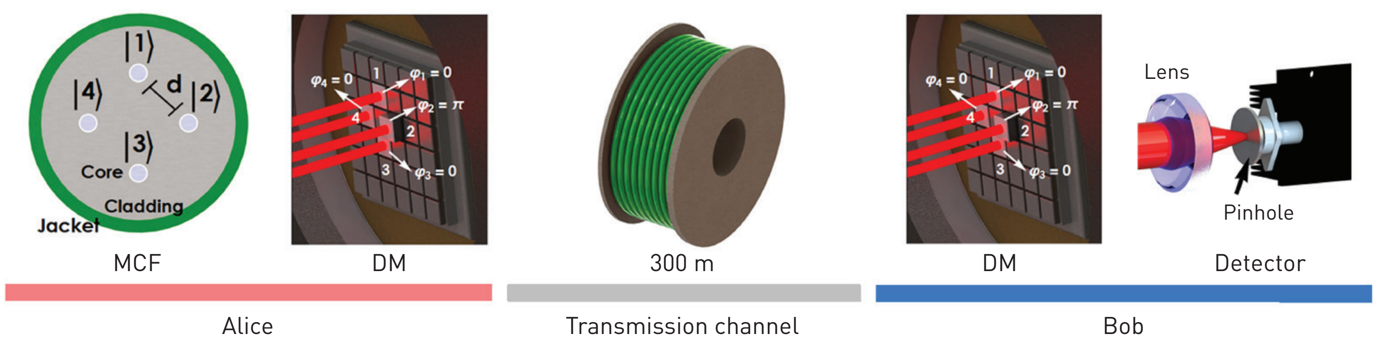

Simplified scheme for long-distance QKD over multicore fiber (MCF). Left: State for Alice, spatially encoded in cross-section of MCF, is prepared for transmission via a deformable mirror (DM). Center: 300 m of MCF forms the transmission channel. Right: Bob's DM changes the measurement setting, and the state transmitted by Alice is projected at the detector.