Laboratory Demonstration of Phase-Time Encoding Quantum Key Distribution System with Multimode Delay Interferometer

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We demonstrate a free-space quantum key distribution (QKD) system based on phase-time encoding by reconfiguring a commercially available fiber-based QKD platform. The main goal of this work is to develop a free-space QKD system with minimal modifications, primarily through the implementation of a free-space multimode delay interferometer at the receiver. The use of a multimode interferometer is crucial for enabling phase encoding over atmospheric channels, where direct coupling into single-mode fibers suffers from prohibitive losses due to atmospheric turbulence and beam distortions.

We review existing methods for detecting spatially distorted quantum states, propose technological improvements, and experimentally evaluate several interferometer designs. A free-space multimode Michelson interferometer with polarization routing is identified as the optimal solution, offering high interference visibility and ease of integration into the system.

A laboratory QKD experiment conducted with the modified system achieved a quantum bit error rate (QBER) of 4.5 % and a stable secret key rate of 800 bit/s, demonstrating the feasibility of secure key distribution over free-space links using adapted fiber-based technology. Detailed theoretical and experimental studies of chromatic and modal dispersion effects confirm that their impact can be effectively managed. This approach provides a practical and scalable route for extending quantum-secure communications into scenarios where optical fiber deployment is impractical or impossible.