# From Turbulence Prediction to Adaptive Correction: Structured Light for High-Dimensional Quantum Communications

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Atmospheric turbulence remains one of the principal obstacles to large-scale free-space quantum communication. While structured photons carrying orbital angular momentum and other spatial degrees of freedom provide access to high-dimensional Hilbert spaces with enhanced information capacity and noise tolerance, these advantages are often compromised by turbulence-induced wavefront distortions and modal crosstalk. In this talk, I will discuss recent progress toward overcoming these limitations using a combination of channel prediction, adaptive correction, and high-dimensional encoding strategies.

Starting from long-term measurements of a 5.4-km urban free-space link, we show how machine-learning models can forecast turbulence conditions hours in advance, enabling intelligent channel management and network operation. I will then present high-speed adaptive optics techniques capable of correcting turbulent distortions in real time and restoring the performance of high-dimensional quantum key distribution protocols. Finally, I will discuss recent advances in scalable spatial-mode encoding, including protocols based on orbital angular momentum, mutually unbiased bases, and position–momentum entanglement, together with the remaining challenges for deploying structured-light quantum networks on metropolitan and satellite scales.

These developments illustrate a pathway from laboratory demonstrations toward practical high-capacity quantum communication systems operating in realistic atmospheric conditions.

## References

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