Multi-dimensional spatial entanglement for secure communications using the conventional optical fiber network

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The future of secure quantum communications requires the distribution of entangled states over long distances. Because of the imminent appearance of quantum computers, being able to easily decipher our current encryption protocols, it is necessary to consider the advantages that quantum entangled states can offer improving our current secure communication networks. Here we transport multi-dimensional entangled states down conventional single-mode fiber (SMF). We achieve this by entangling the spin-orbit degrees of freedom of a bi-photon pair, passing the polarisation (spin) photon down the SMF while accessing multi-dimensional orbital angular momentum (orbital) subspaces with the other.

Spatial mode entanglement has been recognized as a promising resource for quantum communications because of its high-dimensional orthogonal basis increasing the complexity and security of the encrypting protocols. Spatial entangled states transport requires customized fibres and is limited by the decoherence between modes. Here we present how to circumvent this limitation by transporting multi-dimensional spatial entangled states down conventional single-mode fibres [1], by exploiting the so-called spin-orbit hybrid entangled sates. We show in the setup of Fig. 1(a) how to generate such hybrid entangled states, and how the entanglement is preserved by measuring the state's density matrix after 250 m of SMF, as shown in the experimental results of Fig. 1(b) and (c). In this case, we can access two different spatial modes ($\ell = \pm1$ and ±2) by solely changing the spin-orbit coupling optics device, also known as q-plate. Being the topological charge q the one dictating what would be the corresponding OAM mode ℓ that will be coupled into the SMF after traversing the q-plate, given the following conversion relations: $|R,\ell\rangle \xleftrightarrow{q-plate} |L,\ell-2q\rangle$ and $|L,\ell\rangle \xleftrightarrow{q-plate} |R,\ell+2q\rangle$.

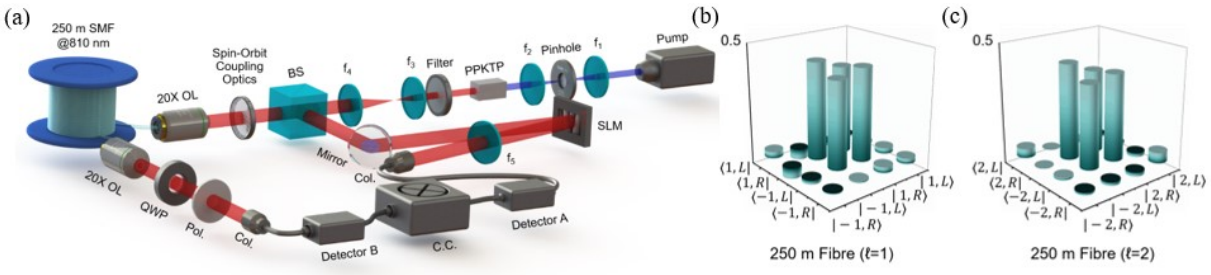

Figure 1(a) Experimental setup for long distance hybrid entanglement transport through SMF, and experimental density matrix reconstruction for (b) ℓ = ±1 and (c) ℓ = ±2.

This work offers an alternative approach to spatial mode entanglement transport that facilitates deployment in legacy networks across conventional optical fiber.

[1] J. Liu, I. Nape, Q. Wang, A. Vallés, J. Wang, and A. Forbes "Multi-dimensional entanglement transport through single-mode fiber", Sci. Adv. (in press).