Development of a digital twin for the NPL quantum network testbed

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Creating quantum networks is difficult due to the fragility and complexity of photonic and quantum-optical systems. NPL is developing a quantum network testbed, paired with a digital twin, to provide rapid prototype testing of hardware and define system requirements. Photon pairs carrying quantum information are generated via spontaneous parametric down-conversion (SPDC) in a nonlinear waveguide. To produce time-bin entanglement, the waveguide is pumped with a pulsed laser whose temporal coherence defines the early/late time-bin structure, while energy-time entanglement is created using a stabilised continuous-wave pump laser with a long coherence length. A key component is the expanded open-source discrete-event simulator, which is essential to defining and validating system performance. Building on the original SeQUeNCe software [1], we derived new modules to model light source, Franson interferometer, and single-photon detector. These allow the simulator to accurately reproduce key performance metrics such as intensity correlation, $G^{(2)}(\tau)$ and Franson-interference fringes under conditions that closely match the physical setup.

We present the application of our extended simulator to the initial phase of the testbed: a controlled table-top prototype configuration implementing a scalable scheme for distributing entanglement among two (Fig. 1) or three users, supported by detailed metrological calibration of the experimental setup. Together, the prototype and its digital twin provide a practical foundation for designing, optimising, and scaling future quantum networks.

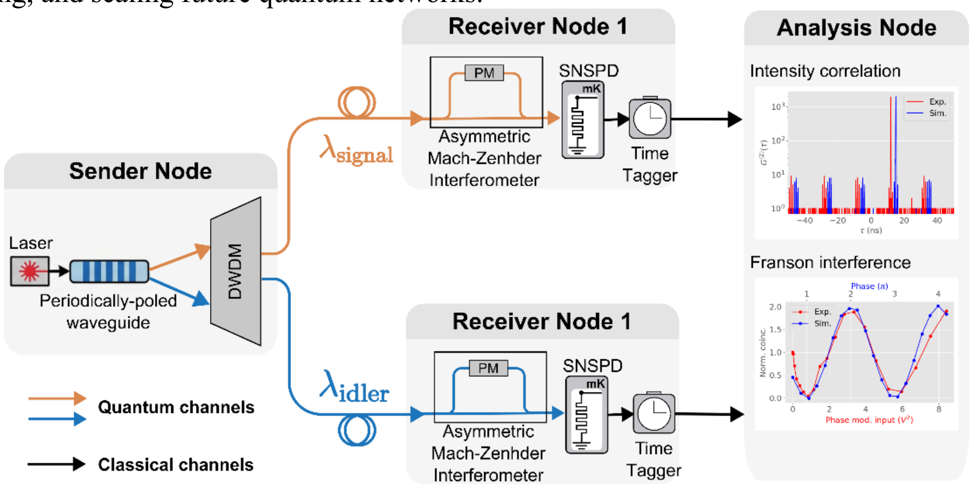

Fig. 1: ***Quantum network***. *The Sender Node generates entangled photon pairs via SPDC, separates them by wavelength using a dense wavelength division multiplexer (DWDM), and distributes them to two Receiver Nodes. Each receiver processes its photon through a scanning AMZI equipped with a phase modulator and a superconducting nanowire single-photon detector, with arrival times recorded by a Time Tagger. This data is then sent to an Analysis Node to calculate the intensity correlation and Franson interference fringes.*

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Reference

[1] Xiaoliang Wu et al., *Quantum Sci. Technol.* 6 045027 (2021).