In order to achieve high information transmission rates in quantum communication networks, it is necessary to send many independent modes through a single physical link using multiplexing techniques. One possible strategy is time-division multiplexing (TDM) [1], which uses photonic time-of-arrival relative to an external clock to identify multiple communication modes. In order to avoid crosstalk in TDM systems, the delay between subsequent modes must be greater than the minimum time resolution of the detection system. In principle, this time scale is as small as the (potentially femtosecond) coherence time of the photon, but it is generally limited in practice by the resolution of the single-photon detectors, which can be on the order of picoseconds [2]. Ultrafast measurement and manipulation techniques are essential to bridge this gap.

The combination of nonlinear optics and pulse chirping provides a robust platform for ultrafast single-photon pulse shaping [3-5]. In one application, sketched in Fig. 1(a), a quantum input signal is strongly chirped and mixed with an oppositely chirped strong escort pulse in a nonlinear material for sum-frequency generation (SFG). The resulting SFG signal has a drastically narrowed spectrum, with a central frequency determined by the relative time delay between the input photon and escort pulse. As a time delay is mapped to a frequency shift, this process acts as a time-to-frequency converter and can be used to convert TDM modes to a frequency comb, shown in Fig. 1(b).

Fig. 1. (a) Time-to-frequency conversion is performed through sum-frequency generation (SFG) between a single photon (red) and a strong escort pulse (orange) with equal-and-opposite chirps applied [4,5]. The resulting upconverted signal is spectrally narrow with a central frequency shift proportional to the relative delay between the inputs. (b) A train of temporally narrow polarization-encoded photonic signals in modes A-C are converted to a frequency comb through time-to-frequency conversion, with the polarization information maintained in each mode [6]. These frequency modes may then be separated using diffraction techniques.

In this work, detailed in [6], we demonstrate a method for demultiplexing a compact pulse sequence of polarization-encoded quantum states using these techniques. We create a train of polarization-entangled photon pairs by pumping a downconversion-based entangled photon source with a sequence of up to three pulses separated by (2.69±0.17) ps. After time-to-frequency conversion, the temporal separations are converted to frequency shifts of (307±19) GHz, which are resolved through simple diffraction and measured with nanosecond-scale detectors. By using a coherent superposition of two sum-frequency processes [7,8], we perform this conversion while maintaining the quantum information stored in the polarization of the multiplexed photon pairs. After conversion, we measure an average quantum state fidelity over the three modes of (92.2±0.3) % when preparing each mode independently and (85.0±0.7) % when preparing the maximally-entangled state in all three modes simultaneously.

References