On-Chip Quantum Autoencoder for Teleportation of High-Dimensional Quantum States

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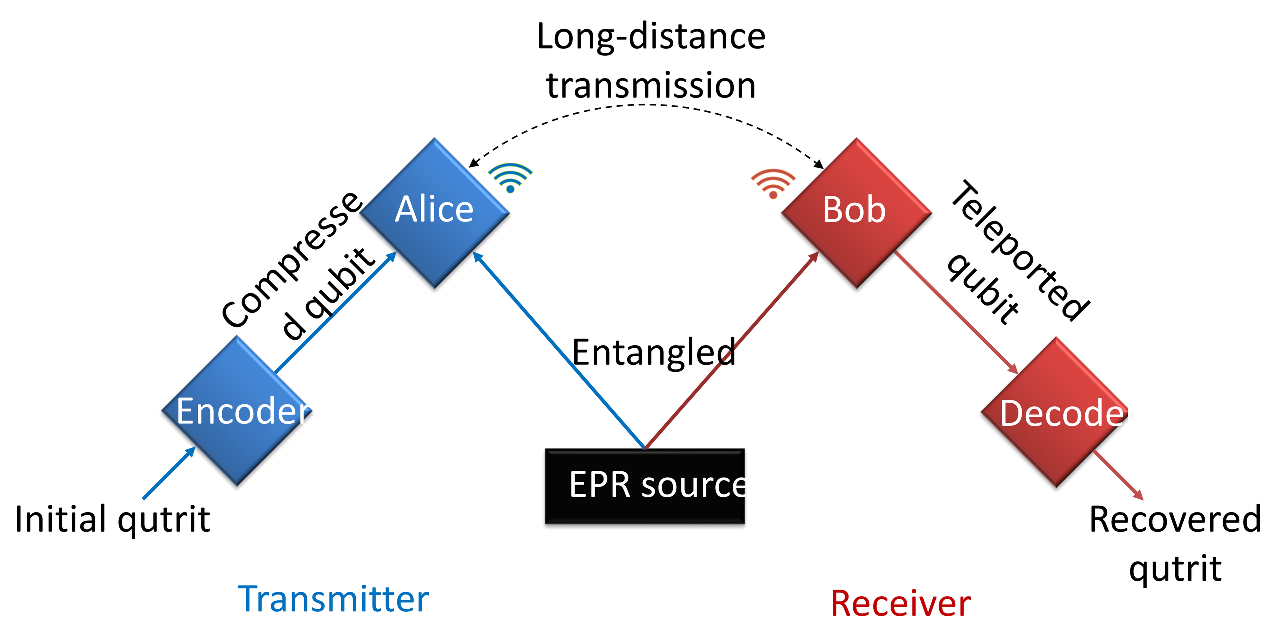
INTRODUCTION AND OBJECTIVES

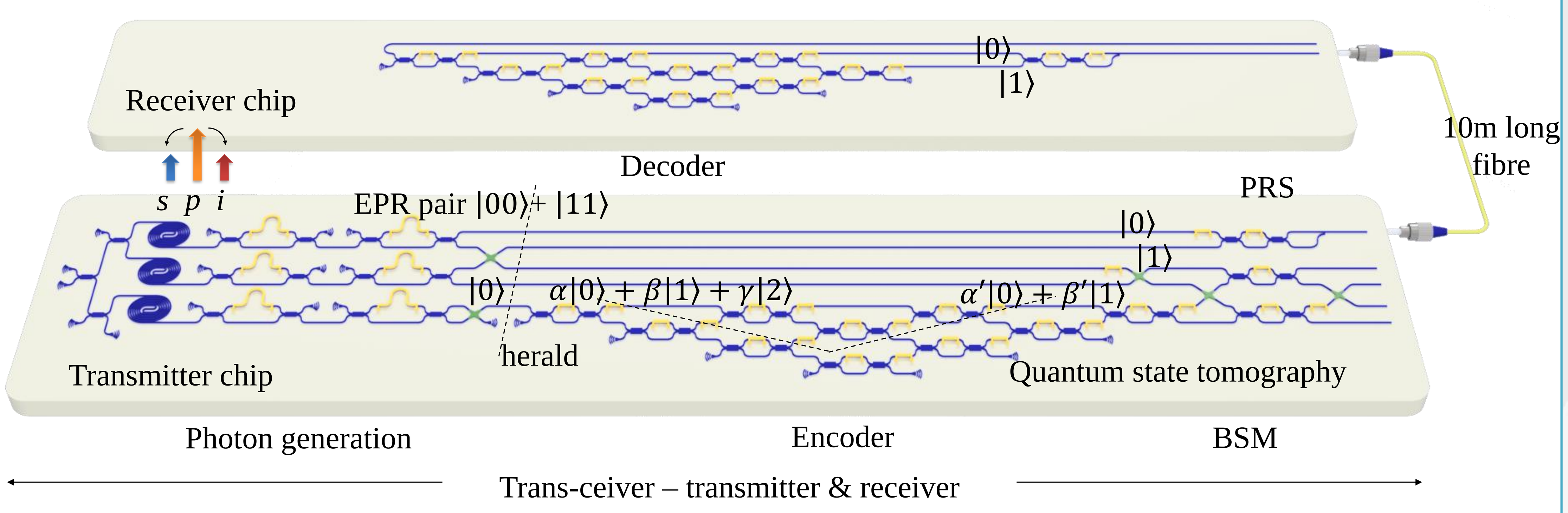
Quantum teleportation is a mechanism to transfer an unknown quantum state from a sender to a receiver via a quantum channel and classical information, which is a crucial protocol for the physical implementation of many quantum communication and quantum computation schemes. Most teleportation experiments are based on qubits, while teleporting higher-dimensional quantum states is difficult. The conceptual proposal by Bennett et al. has great challenge in implementing high-dimensional Bell state measurement, for which two recent experiment demonstrations are generalized. Here, we propose a totally different way, using a quantum autoencoder to efficiently teleport a qutrit. The key strategy is to reduce the dimension of the input states by erasing redundant information and reconstruct to the high-dimension after chip-to-chip teleportation. The autoencoder is trained across a training set of data and with single shot measurements, to erase some bits of the original inputs without abandoning useful information (which affects the reproduction). After training, we can teleport any further states and reconstruct them with high fidelity.

PROTOCOL



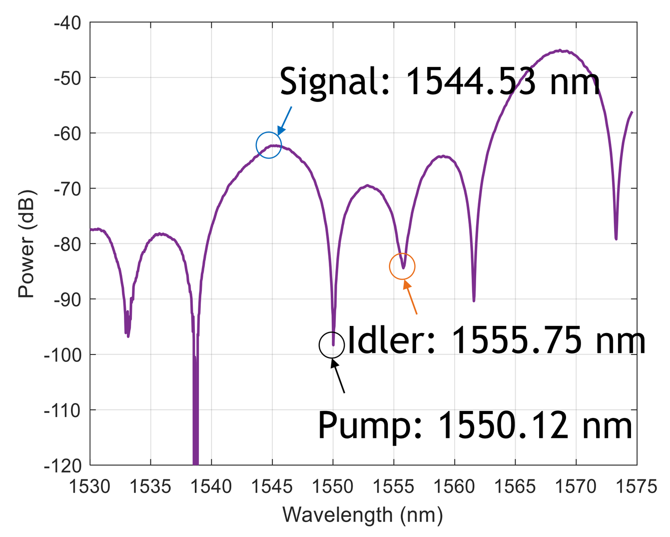
The overarching idea of QAFT. The transmitter and the receiver each hold half of an Einstein-Podolsky-Rosen (EPR) pair. At the transmitter, the initial qutrit is compressed into qubit by the trained encoder, and BSM is performed. Depending on BSM results and the encoder, the receiver will set up the decoder and reconstruct the initial qutrit from the teleported qubit.

CHIP DESIGN & FABRICATION

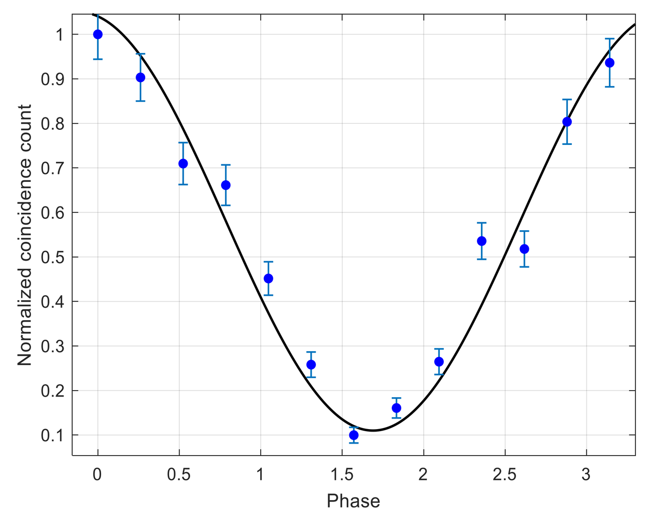


The schematic of the quantum teleportation chip which consists of two sub-chips the transmitter and the receiver. Different functionalities are realized, including the input state preparation, the independently programmable encoder and decoder, and the Bell projection operator and the PRC connecting between transmitter and receiver. The transmitter chip and receiver chip are functionally independent, while integrated to enable two-way communication.

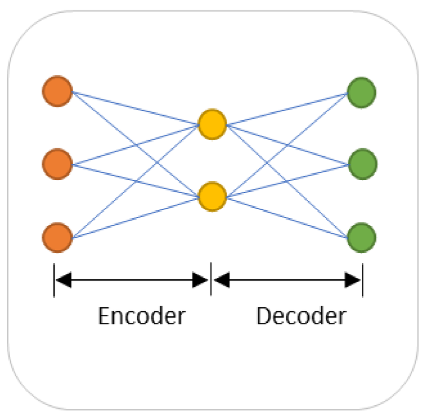
TESTING RESULTS

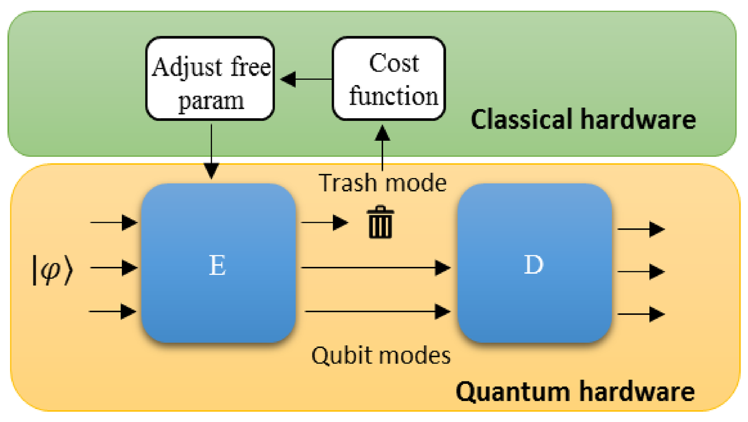


Asymmetric MZIs can filter the pump light and demultiplex the signal and idler photons.

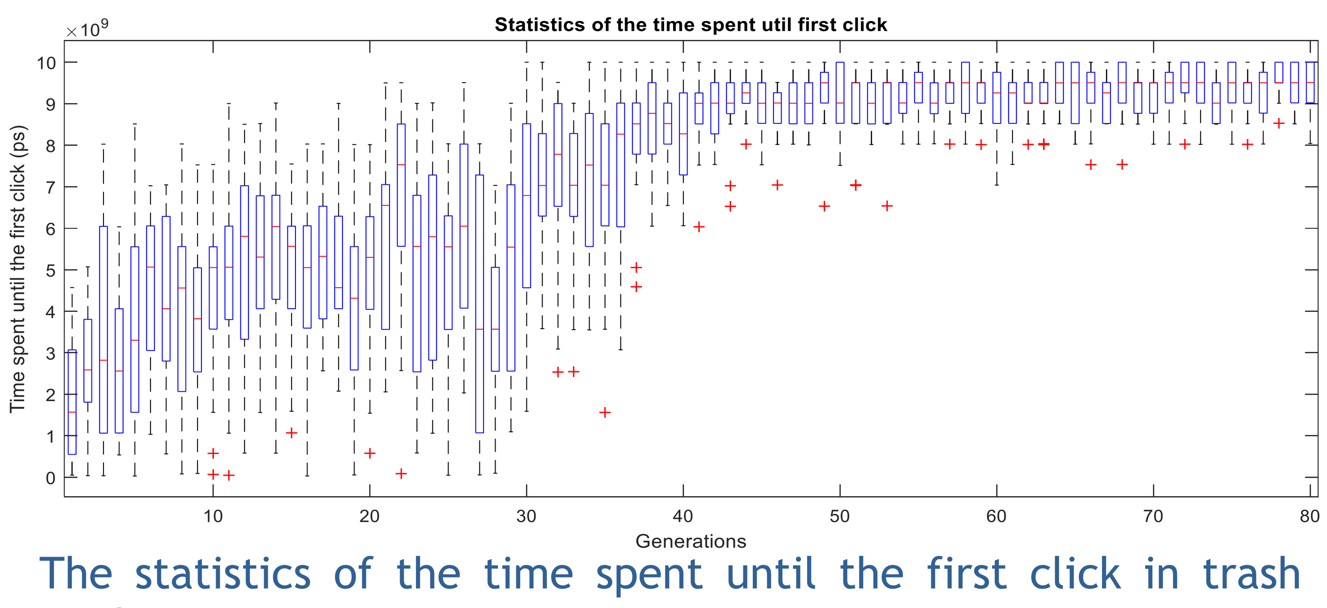


Measured visibility of the heralded quantum interference.

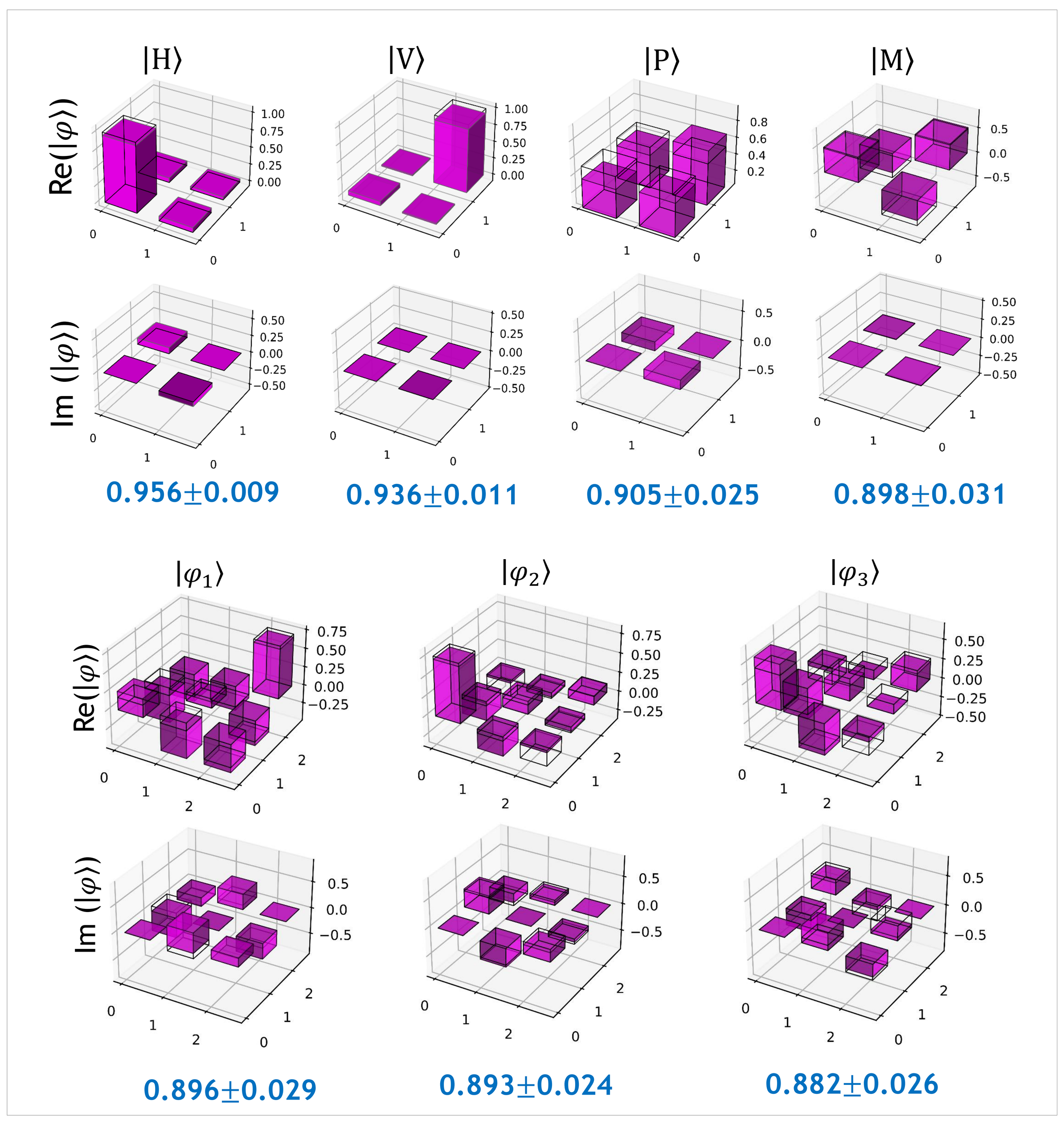




The autoencoder represented by a graph of interconnected groups of nodes. The training scheme of the quantum autoencoder. The autoencoder consists of an encoder (E) for compression and a decoder (D) for restoration, respectively.



The statistics of the time spent until the first click in trash mode across iterations.



Chip-to-chip teleportation results. The teleported qubit was decoded to recover the original generated qutrit on the receiver chip, with a fidelity of 0.894±0.026.

CONCLUSIONS

We have demonstrated a silicon photonic chip that realizes the teleportation of a high-dimensional quantum states by compressing the input qutrit losslessly to a qubit using a well-trained quantum autoencoder. The produce, process, transmit and measure of the photon states are integrated on a single chip. The encoder after training achieves compression on the qutrit to qubit, with a reconstruction fidelity of ~0.971. Long distance is placed between transmitter and receiver by path-polarization conversion techniques. The fidelity between the decoded qutrit and the original qutrit is ~0.894. Our scheme will come in handy for quantum internet, cryptography and transferring quantum computer states.