Experimental demonstration of entanglement delivery using a quantum network stack

QIRG | IETF 116

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TU Delft QuTech QIA QUANTUM INTERNET ALLIANCE

Outline

- Background and goals
- Programmable quantum network nodes
- Implementation of a quantum networking stack
- Experimental results
- Future work

Note

This presentation is based on:

Experimental demonstration of entanglement delivery using a quantum network stack

M. Pompili, C. Delle Donne, I. te Raa, B. van der Vecht, M. Skrzypczyk, G. M. Ferreira, L. de Kluijver, A. J. Stolk, S. L. N. Hermans, P. Pawełczak, W. Kozlowski, R. Hanson, S. Wehner

npj Quantum Information 8.1 (2022)

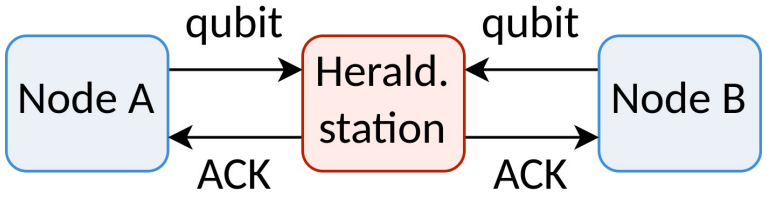
DOI: 10.1038/s41534-022-00631-2

Background and goals

Ingredients

Assumptions:

- Entanglement-based quantum networks
- Heralded entanglement generation



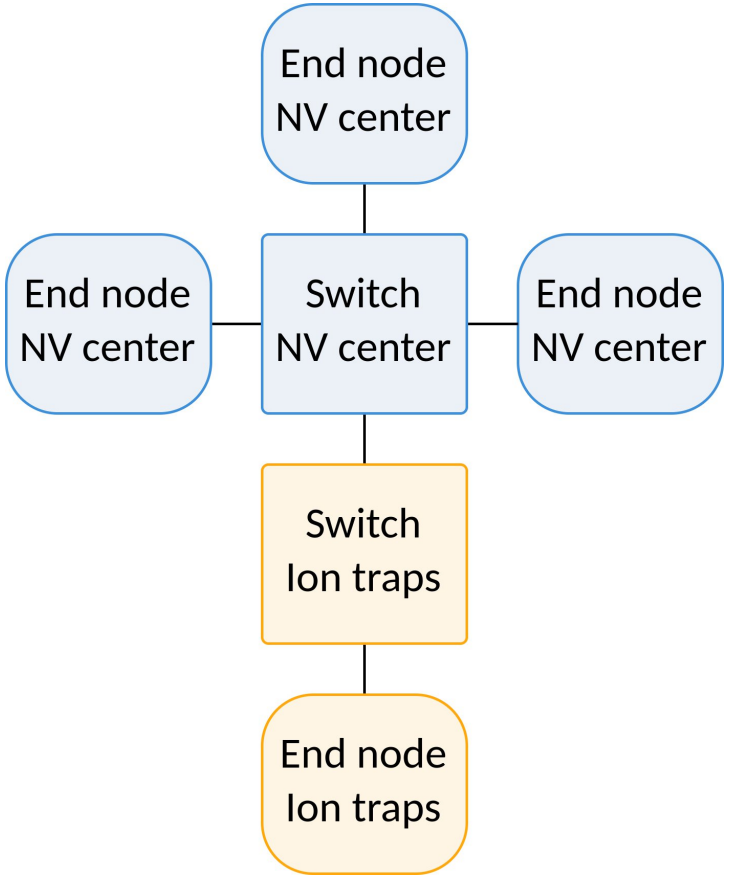
Existing tools:

- Multi-node quantum networks (e.g. [1])
- Protocol designs for quantum data plane (e.g. [2, 3])

[1] "*Realization of a Multinode Quantum Network of Remote Solid-State Qubits*". Pompili et al., Science 372.6539 (2021)
[2] "*A Link Layer Protocol for Quantum Networks*". Dahlberg et al., SIGCOMM (2019)
[3] "*Designing a Quantum Network Protocol*". Kozlowski et al., CoNEXT (2020)

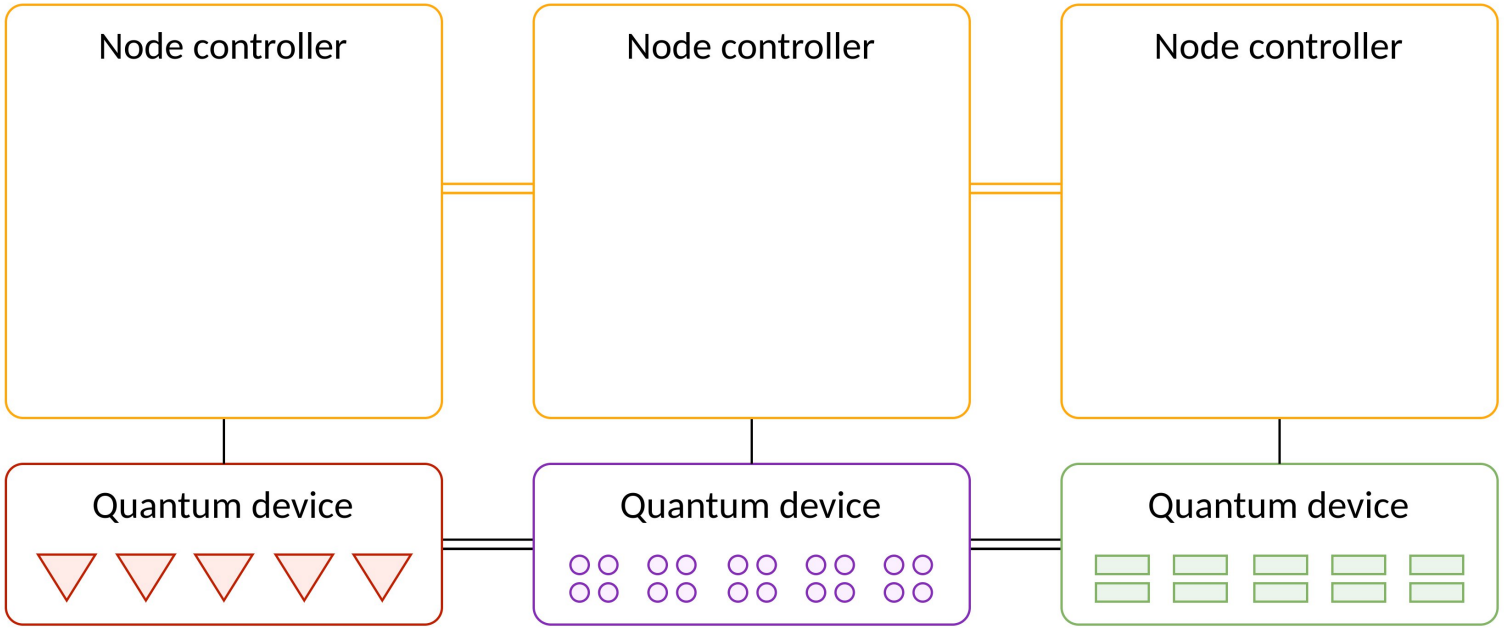
Goals

- **Heterogeneous quantum networks**
  Control end nodes and switches that are based on various quantum platforms
- **Programmable network nodes**
  Control of nodes must be platform-independent and application-agnostic (not ad-hoc)
- **Configurable resource allocation**
  Node resources are allocated according to local demand and global needs

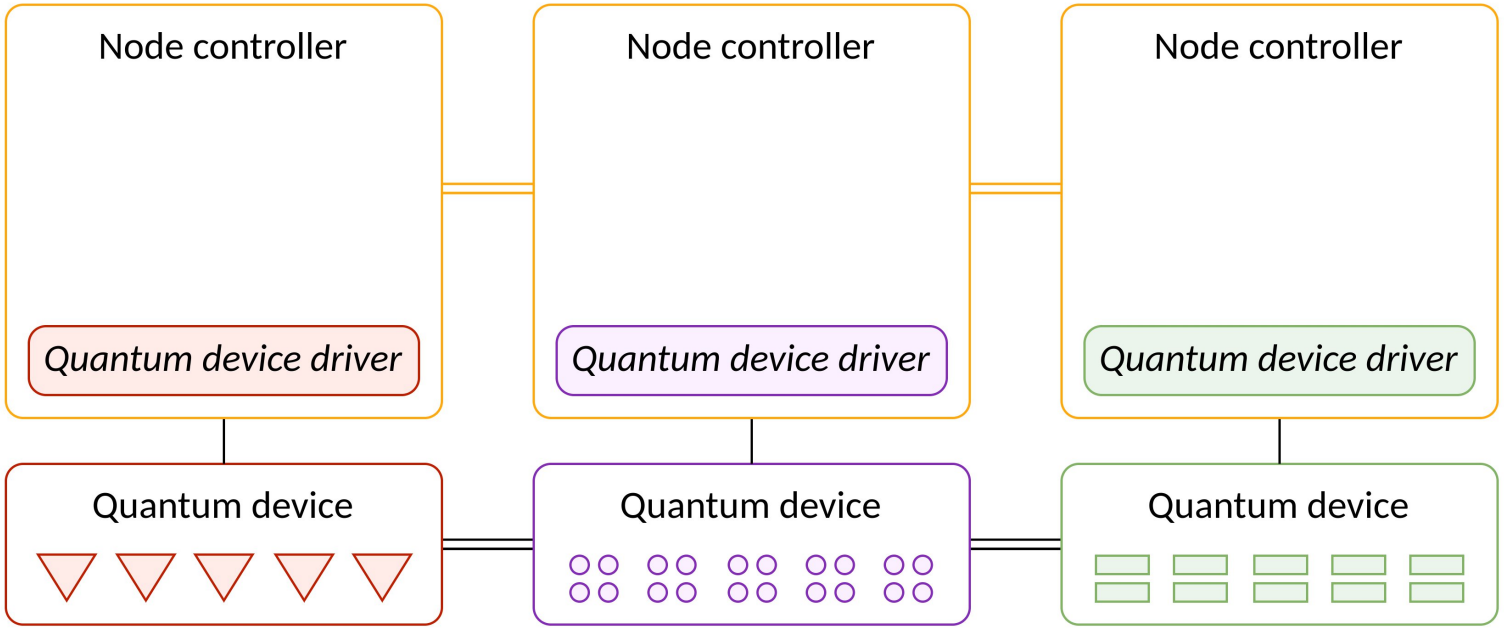


Programmable quantum network nodes

Programmable quantum network

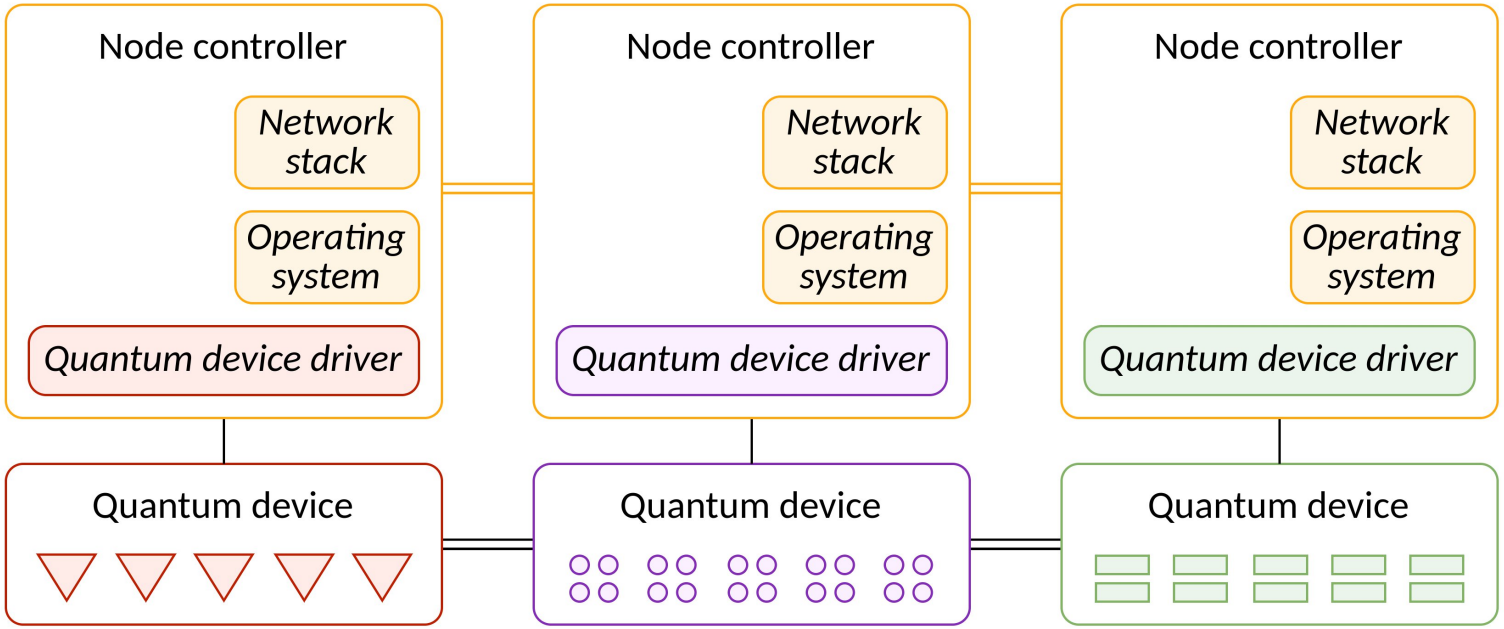


Programmable quantum network



Heterogeneous quantum networks

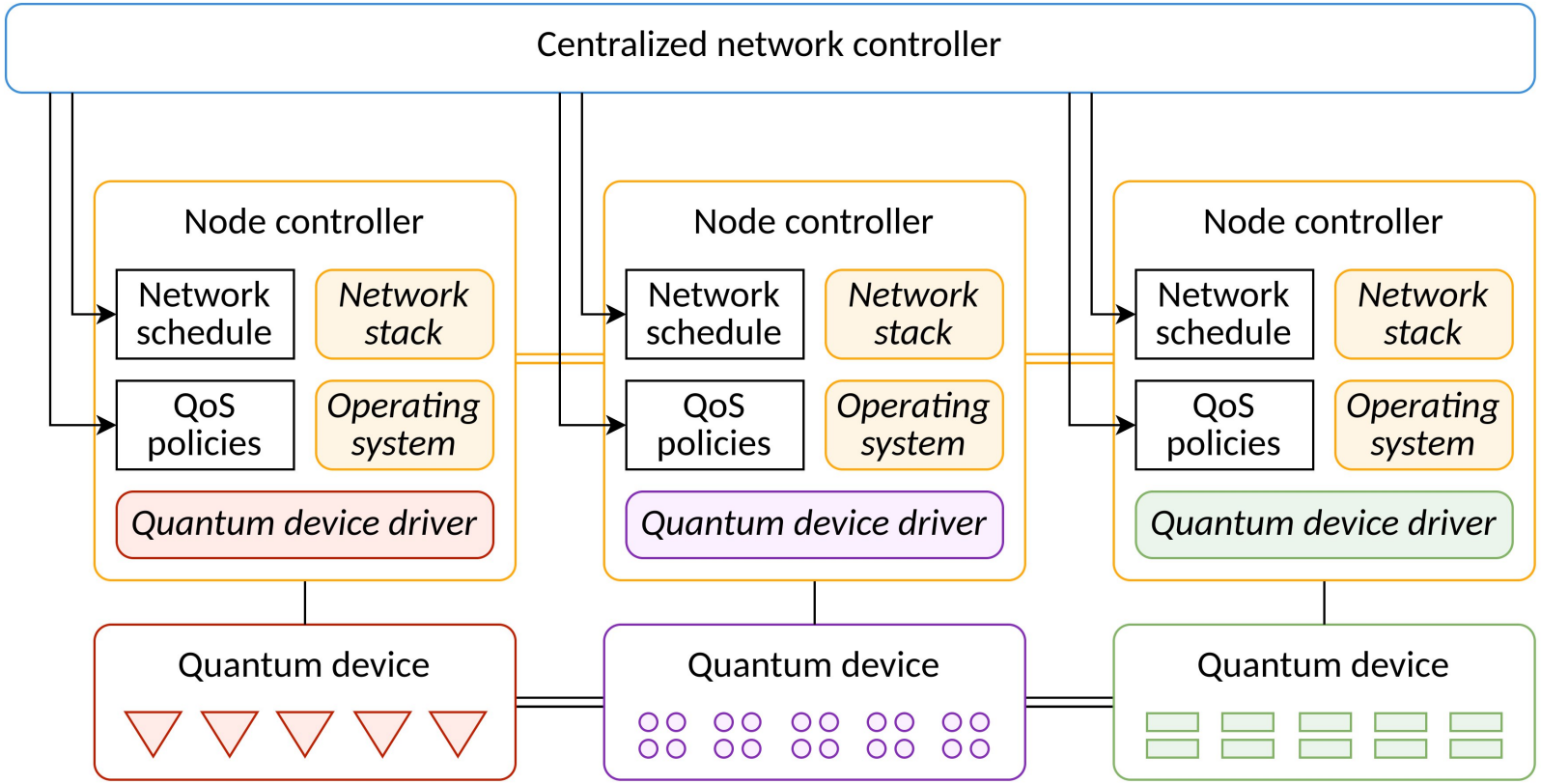
Programmable quantum network



Programmable network nodes

Heterogeneous quantum networks

Programmable quantum network

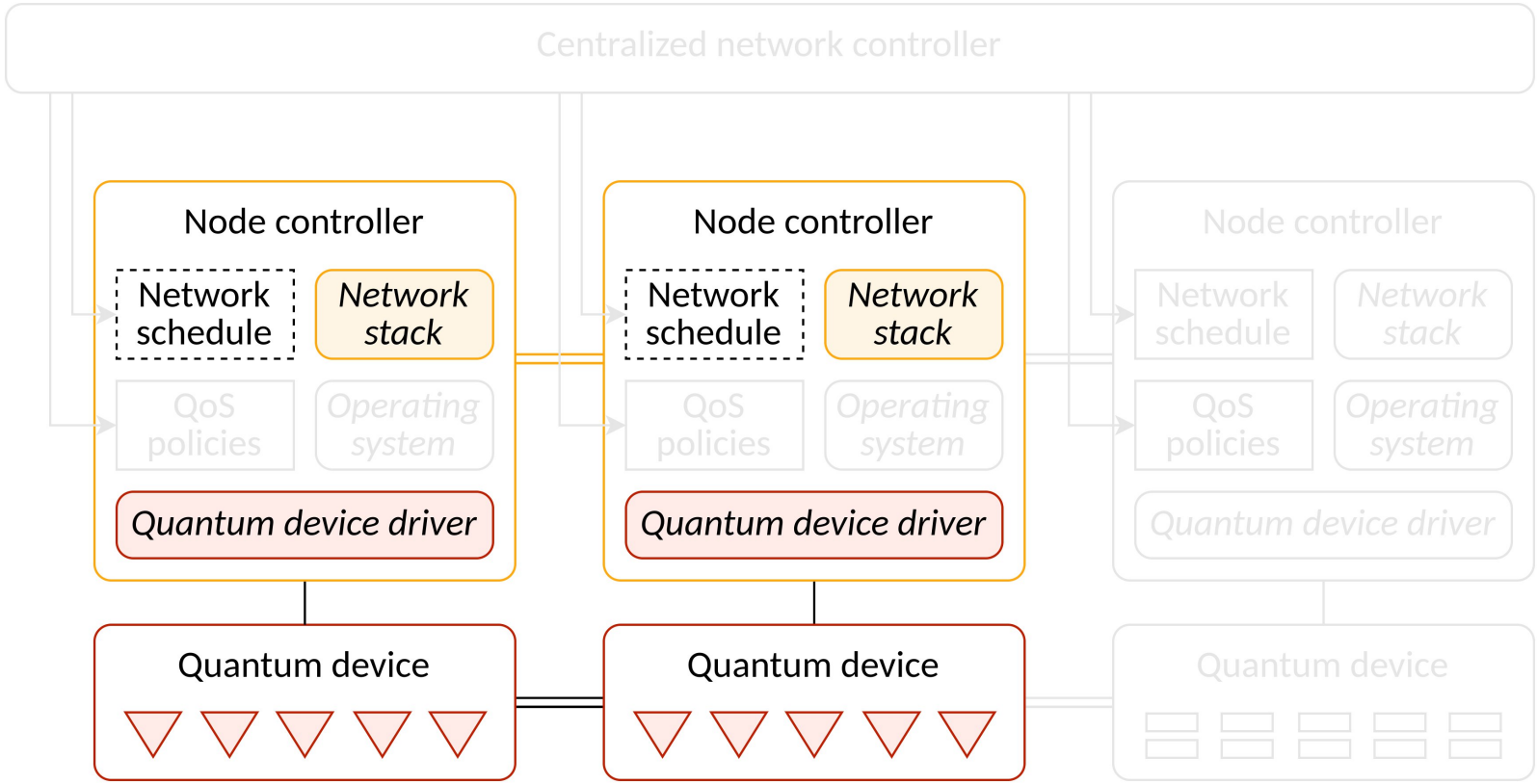


Configurable resource allocation

Programmable network nodes

Heterogeneous quantum networks

Programmable quantum network



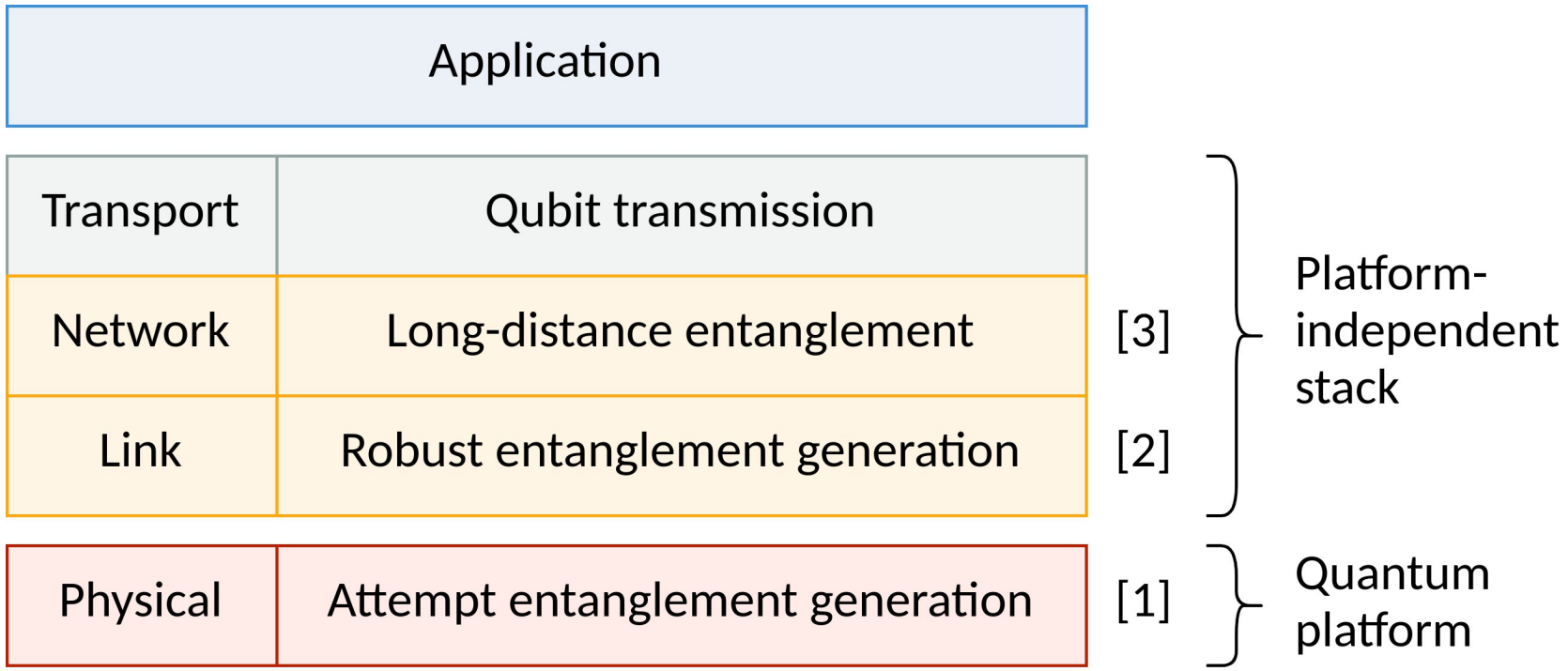
Configurable resource allocation

Programmable network nodes

Heterogeneous quantum networks

Implementing a quantum networking stack

A quantum network stack



[1] "*Realization of a Multinode Quantum Network of Remote Solid-State Qubits*". Pompili et al., Science 372.6539 (2021)
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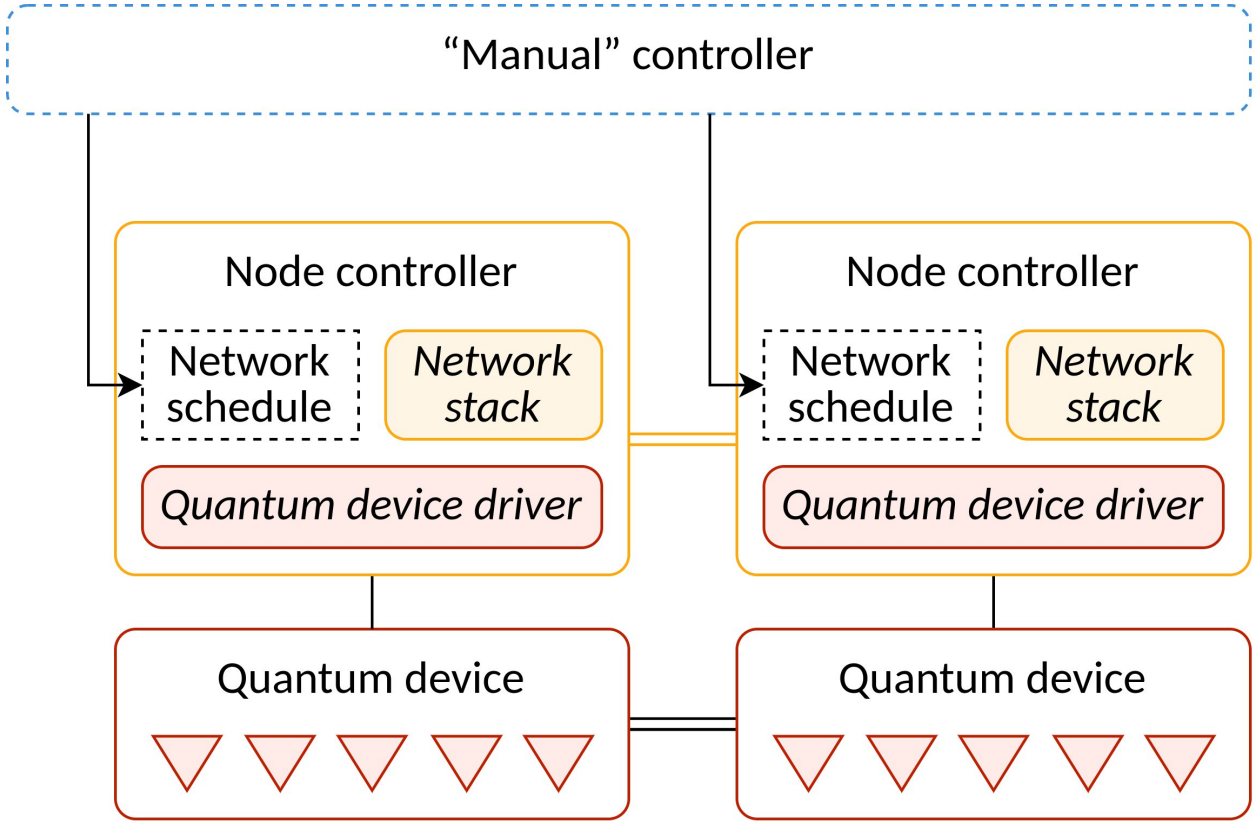
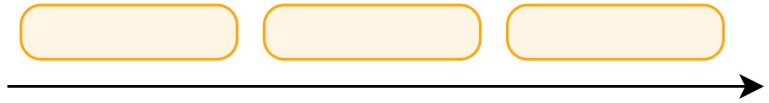
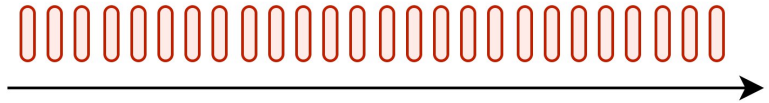
Time domains and synchronization



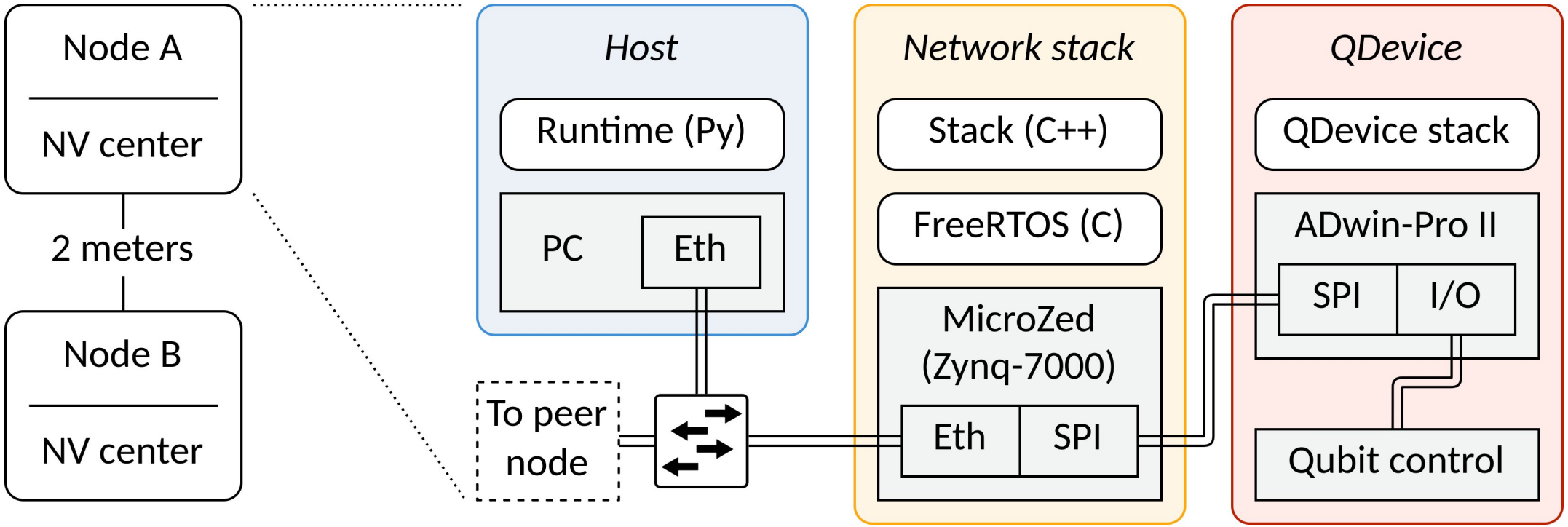
Network schedule
- timeslots with millisecond resolution
- generated on control plane



Entanglement attempts
- triggered at nanosecond resolution
- synchronized across two nodes



Deployment


Node A
NV center
2 meters
Node B
NV center
To peer node
Host
Runtime (Py)
PC
Eth
Network stack
Stack (C++)
FreeRTOS (C)
MicroZed (Zynq-7000)
Eth
SPI
QDevice
QDevice stack
ADwin-Pro II
SPI
I/O
Qubit control

Experimental results

Applications and metrics

Applications:

- Entanglement requests at various fidelities
- Full tomography of entangled state
- Remote state preparation

Metrics:

- Quantum performance → fidelity of entangled state
- Classical performance → entanglement request latency

Applications and metrics

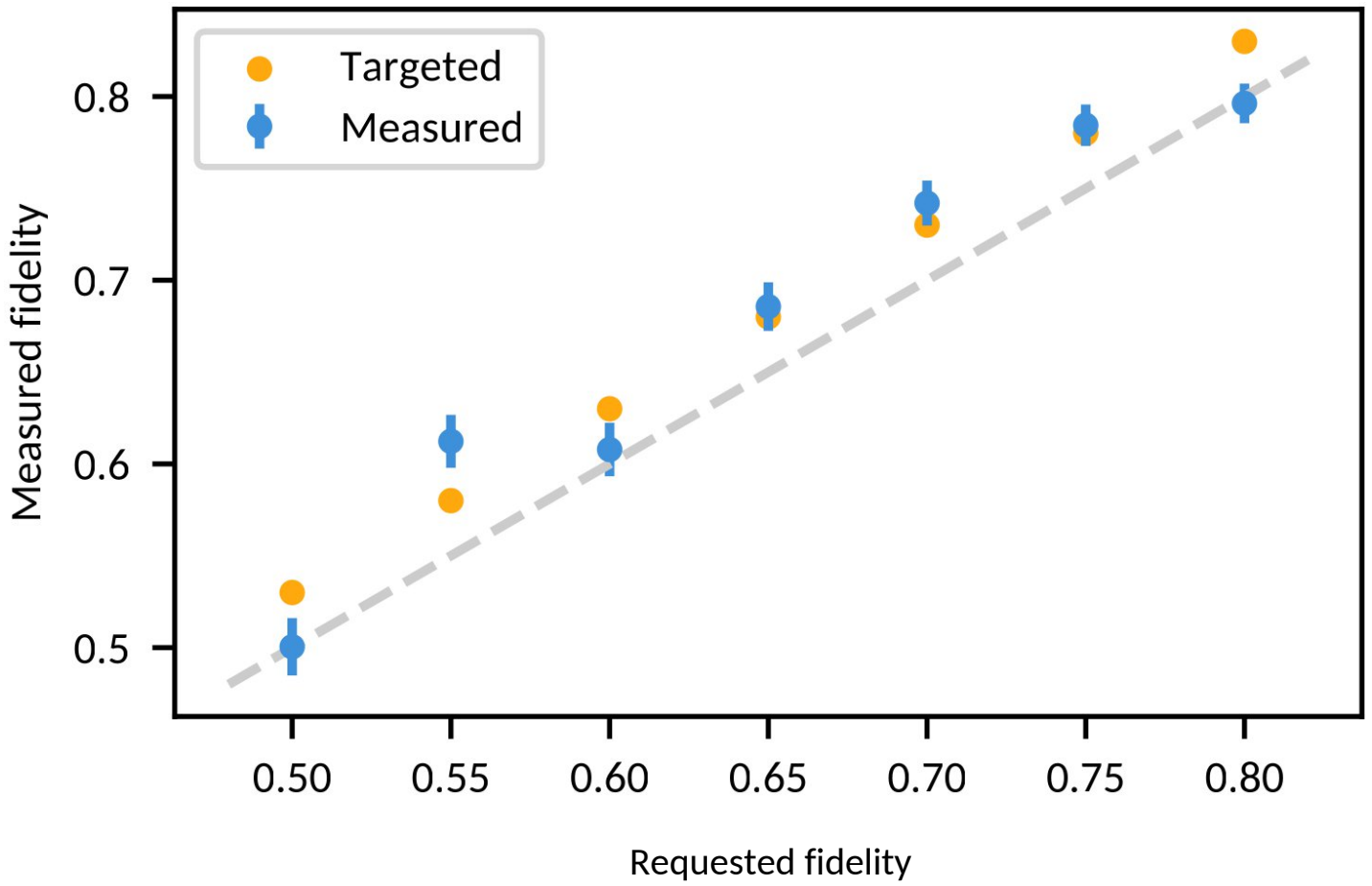
Simplified application code (uses NetQASM SDK [4])

```
req_fidelities = [0.50 , 0.55 , 0.60 , 0.65 , 0.70 , 0.75 , 0.80]
meas_bases = [(-X, -X), (-X, +X), (-Y, -Y), (-Y, +Y), ...]

for rep in range(125):
    for fid in req_fidelities:
        for meas in meas_bases:
            client_basis = meas[0]
            client_qubit = create_ent(min_fidelity=fid)
            client_qubit.rotate_basis(client_basis)
            outcomes[rep, fid, meas] = client_qubit.measure()
```

[4] "*NetQASM*". Dahlberg et al., Quantum Sci. Technol. 7 (2022) — github.com/QuTech-Delft/netqasm

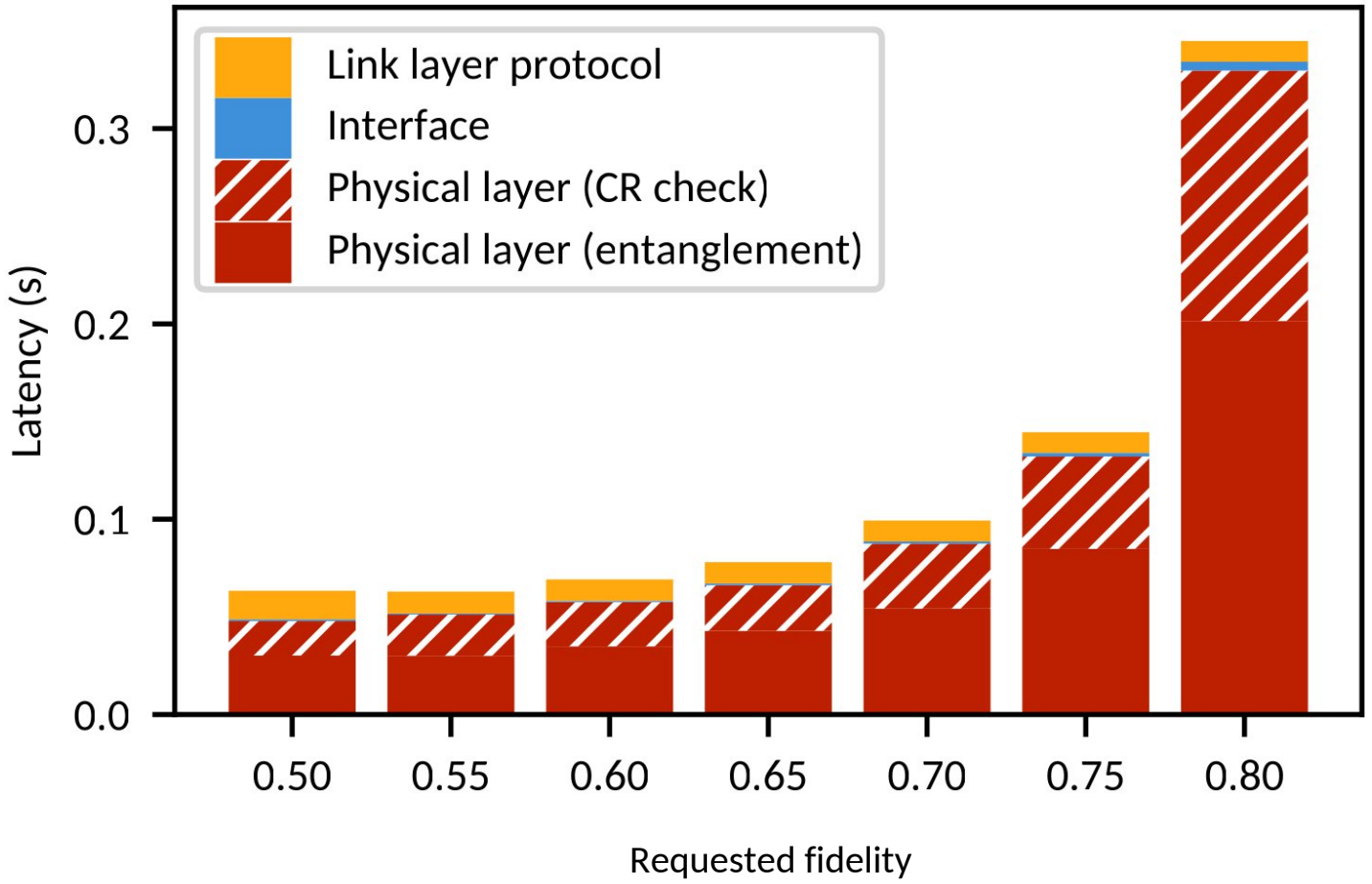
Results: Measured fidelity



Targeted: physical layer tries to deliver fidelity higher than requested

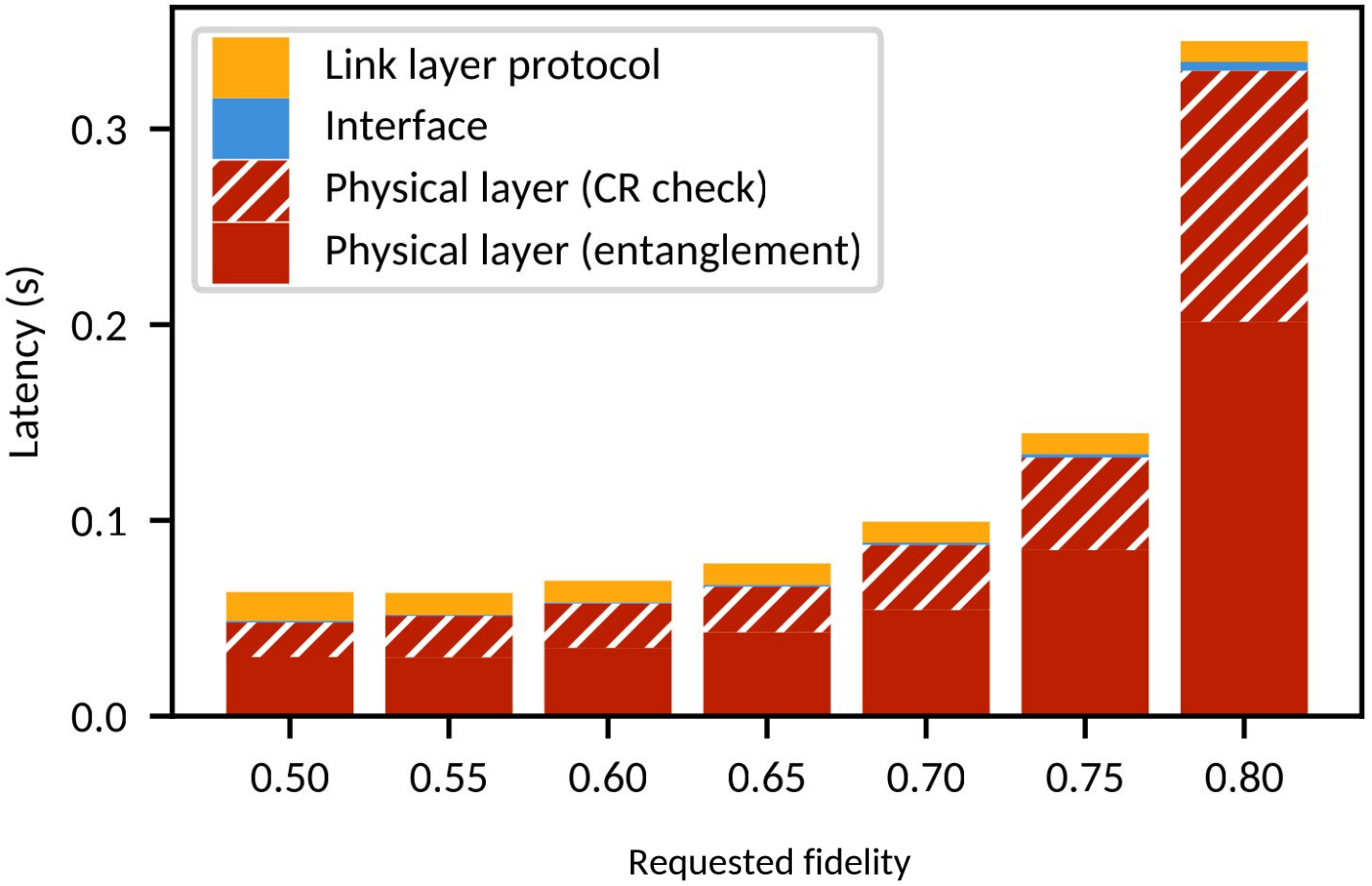
Measured: almost always larger than requested 🎉🎉

Results: Latency breakdown

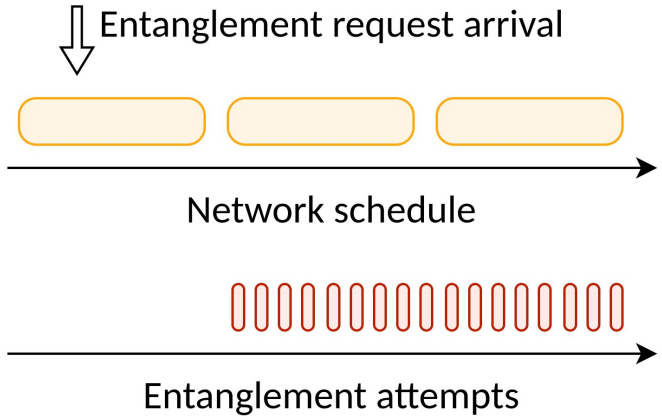


Physical layer: overhead increases with requested fidelity

Results: Latency breakdown



Link layer: roughly constant overhead



Future work

Future work

- Operating system for quantum network nodes (ONGOING)
- More complex applications / concurrent applications (ONGOING)
- Larger-scale experiments (> 2 nodes at least)
- Node- and network-level scheduling
- Design and implementation of control plane

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