Leveraging Internet Principles To Build a Quantum Network

Speaker:

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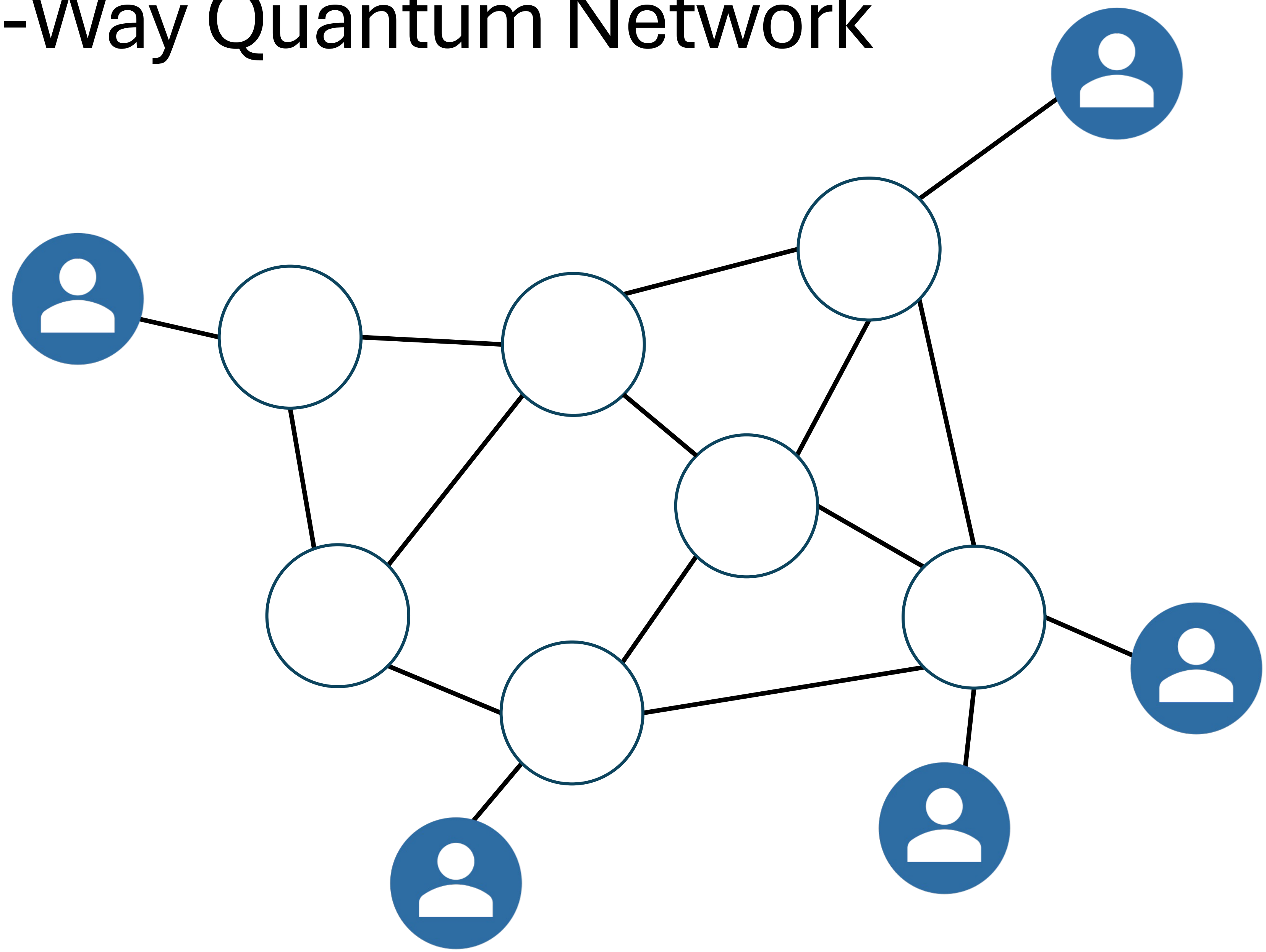
[1] Bacciottini *et al.*, IEEE Network, arXiv:2410.08980

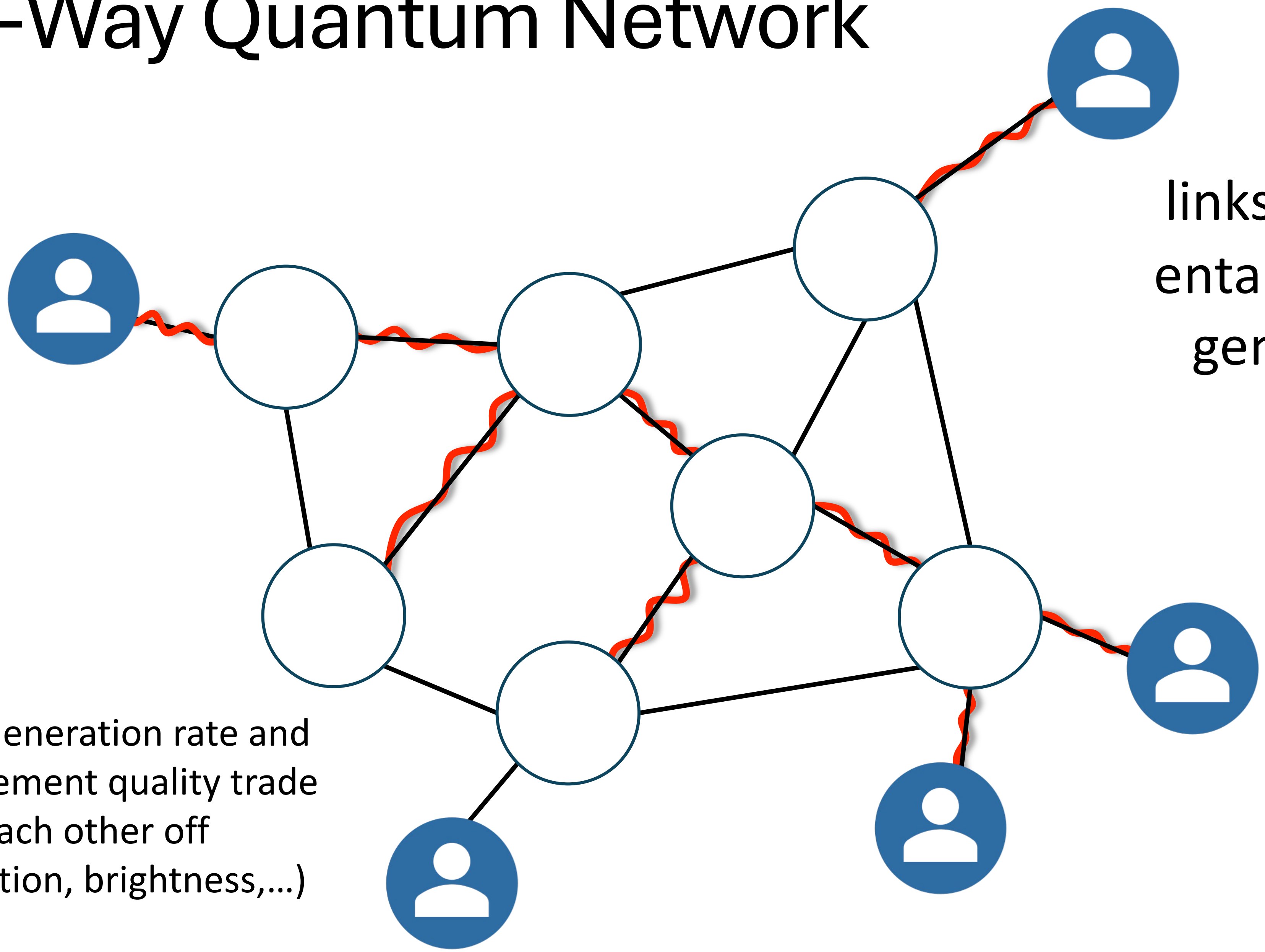
[2] Panigrahy *et al.* (under review), arXiv:2510.09371

Collaborators: Don Towsley, G. Vardoyan, S. Krastanov, N. Panigrahy, N. Rao, C. Hollot *et al.*

2-Way Quantum Network



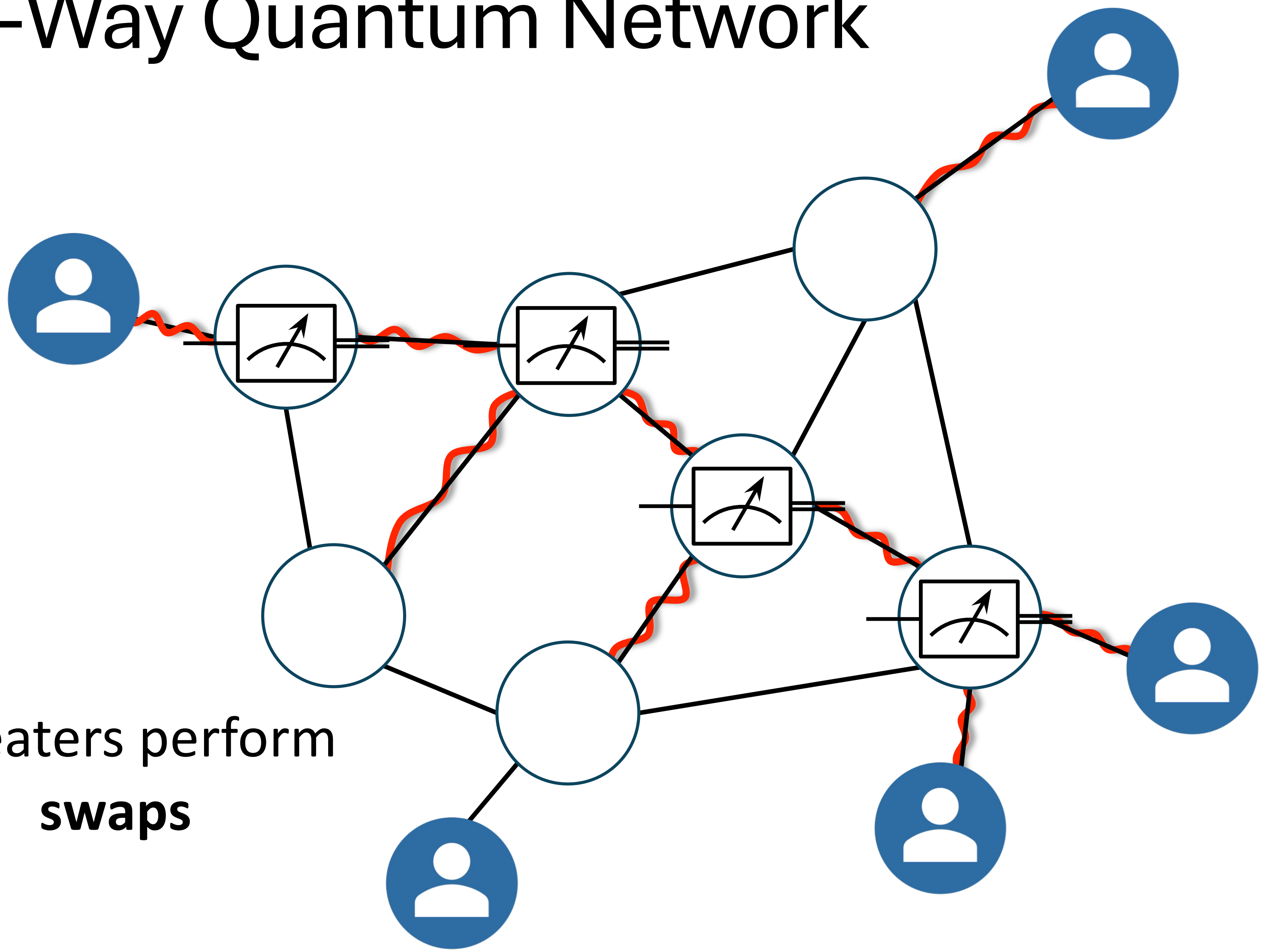
2-Way Quantum Network



links attempt entanglement generation

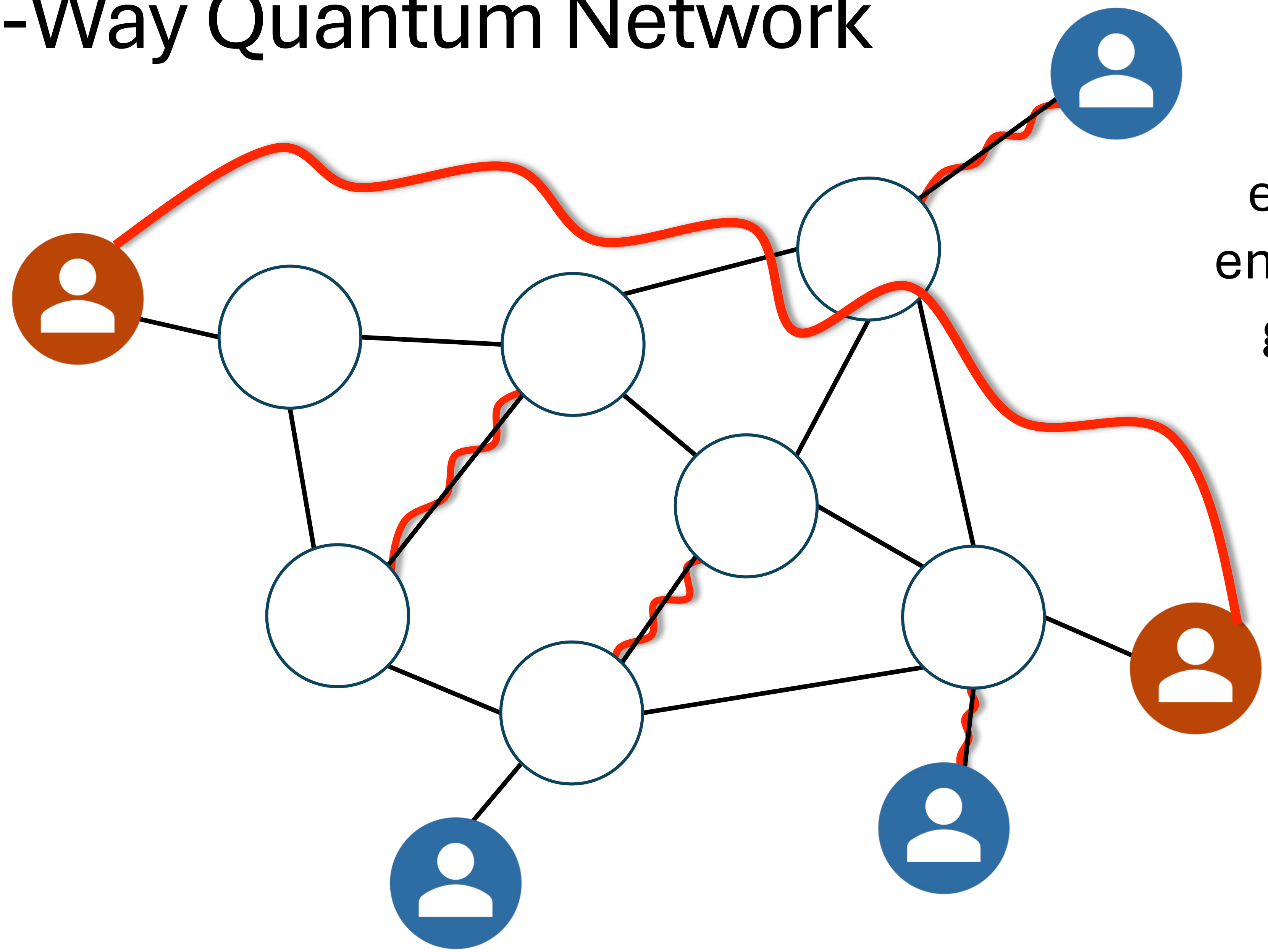
Note: Generation rate and entanglement quality trade each other off (distillation, brightness,…)

2-Way Quantum Network



repeaters perform **swaps**

2-Way Quantum Network



end-to-end
entanglement
generated

Connectionless: Why?

- What is a connectionless (quantum) network?
  1. Little/no application state at switches/repeaters
  2. Each application request treated separately

- Why connectionless?
  1. Simple operation, high utilization
  2. It already proved winning: the **Internet is connectionless**!

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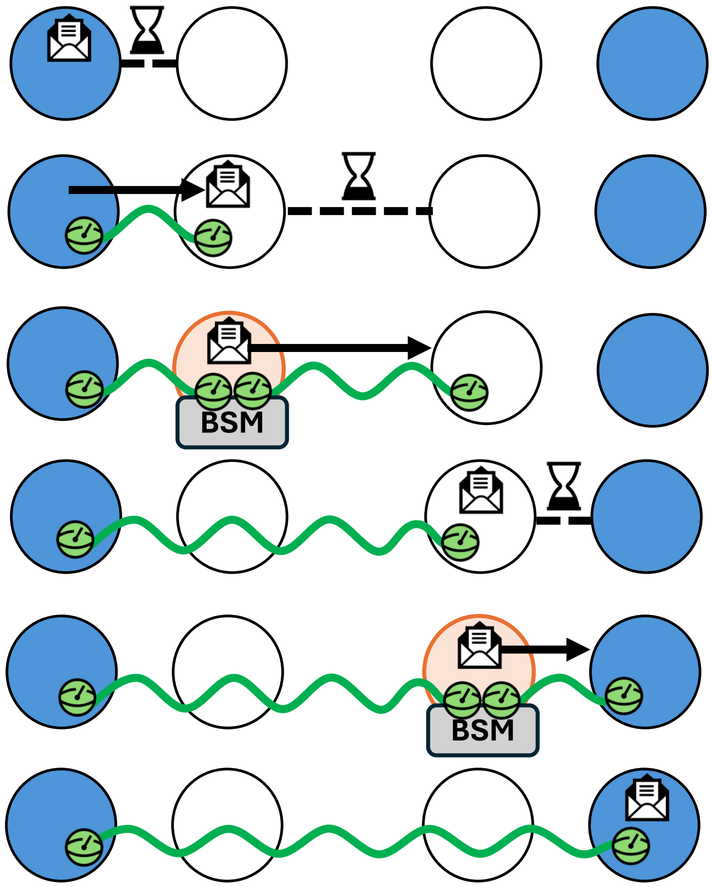
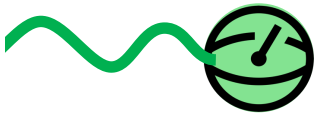
Q: How do we design a connectionless 2-way quantum network?
A: The key is sequential (cascaded) swap schedule

Sequential Swapping



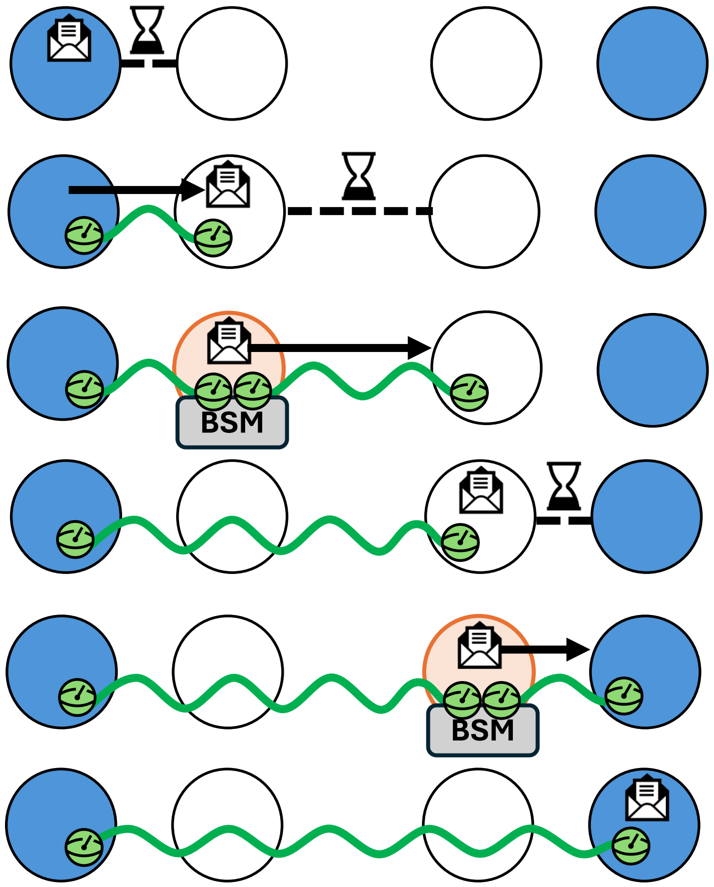
- Two types of data is ”moved” towards the destination node:

 **Quantum**: Entangled qubit state

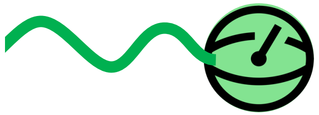
 **Classical**: dest address, correction bits, …

[3] De Andrade *et al.*, arXiv:2405.18252
[1] Bacciottini *et al.*, IEEE Network, arXiv:2410.08980

Sequential Swapping



- As if two types of data were ”moved” towards the destination node:



Quantum: Entangled qubit state

Classical: dest address, correction bits, ...

Abstraction:

- Quantum + Classical → Q-Datagram
- Swap → Q-Datagram Forwarding

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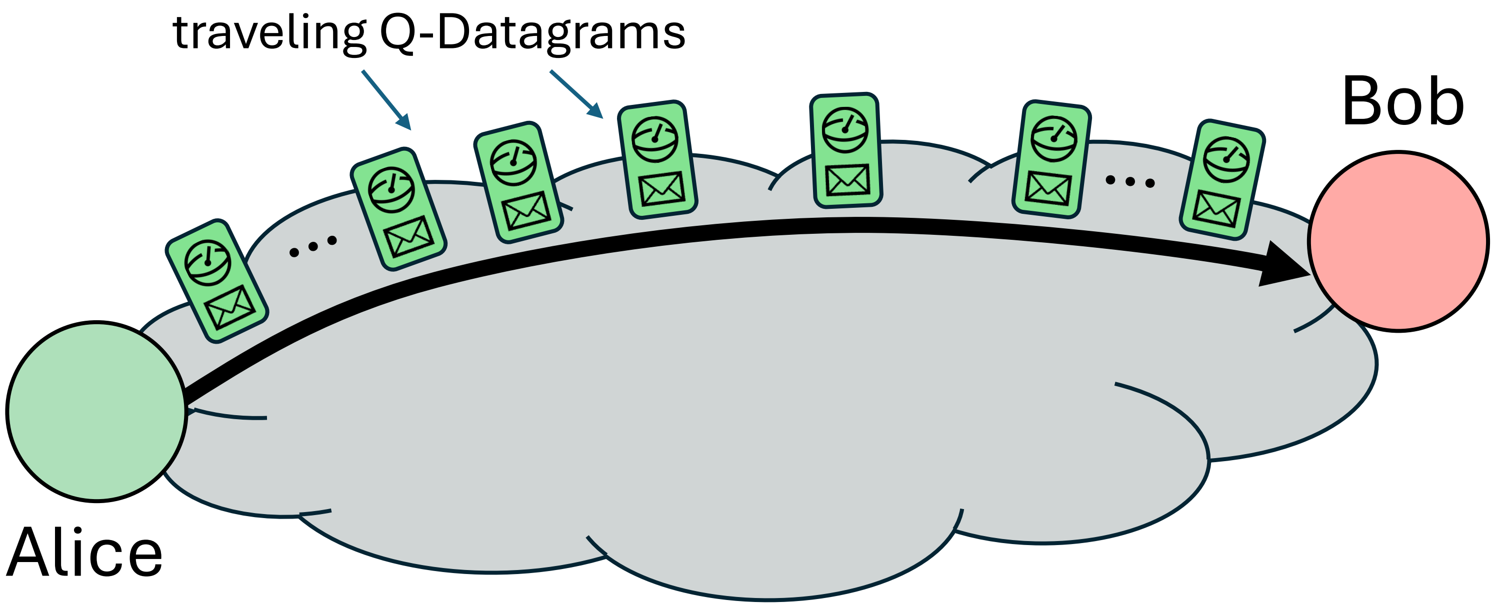
A Packet-Switched Quantum Network

- Network contains many traveling Q-Datagrams
- Each Q-Datagram maps to a qubit stored in some node’s memory



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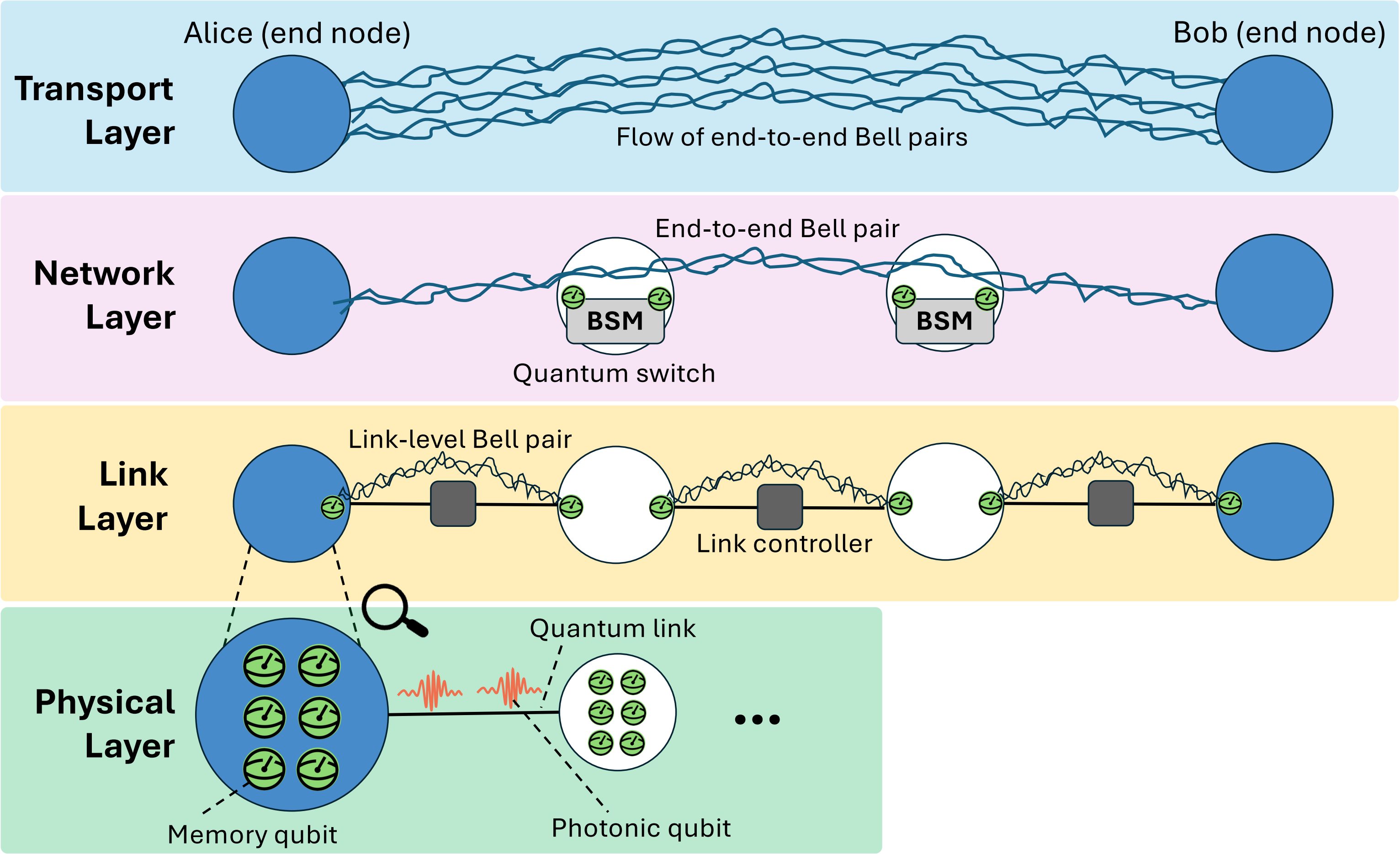
Protocol Stack

[4] A. Dahlberg *et al.*, "A Link layer protocol for quantum networks", SIGCOMM '19, ACM, 2019

[5] R. Van Meter *et al.*, "A quantum Internet architecture", QCE, 2022



- **E2E flows of entanglement**
- **E2E entanglement**
- **Link entanglement generation**
- **Quantum operations**

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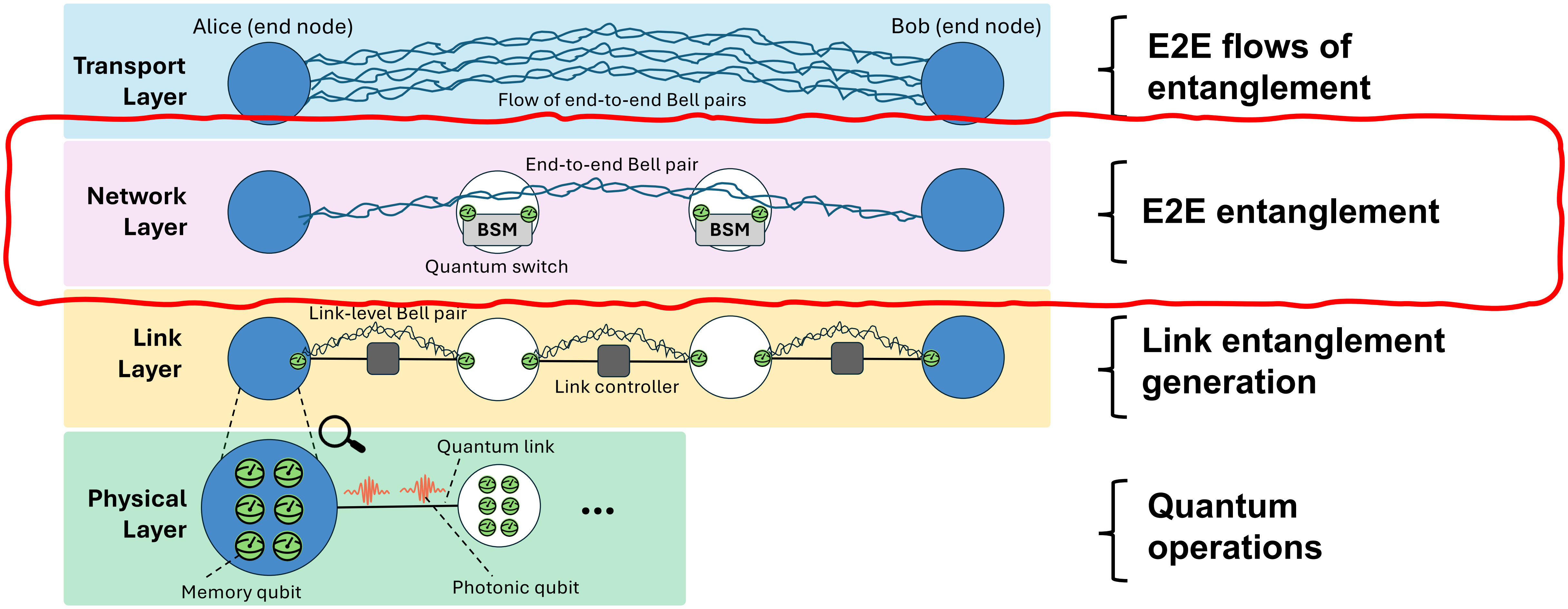

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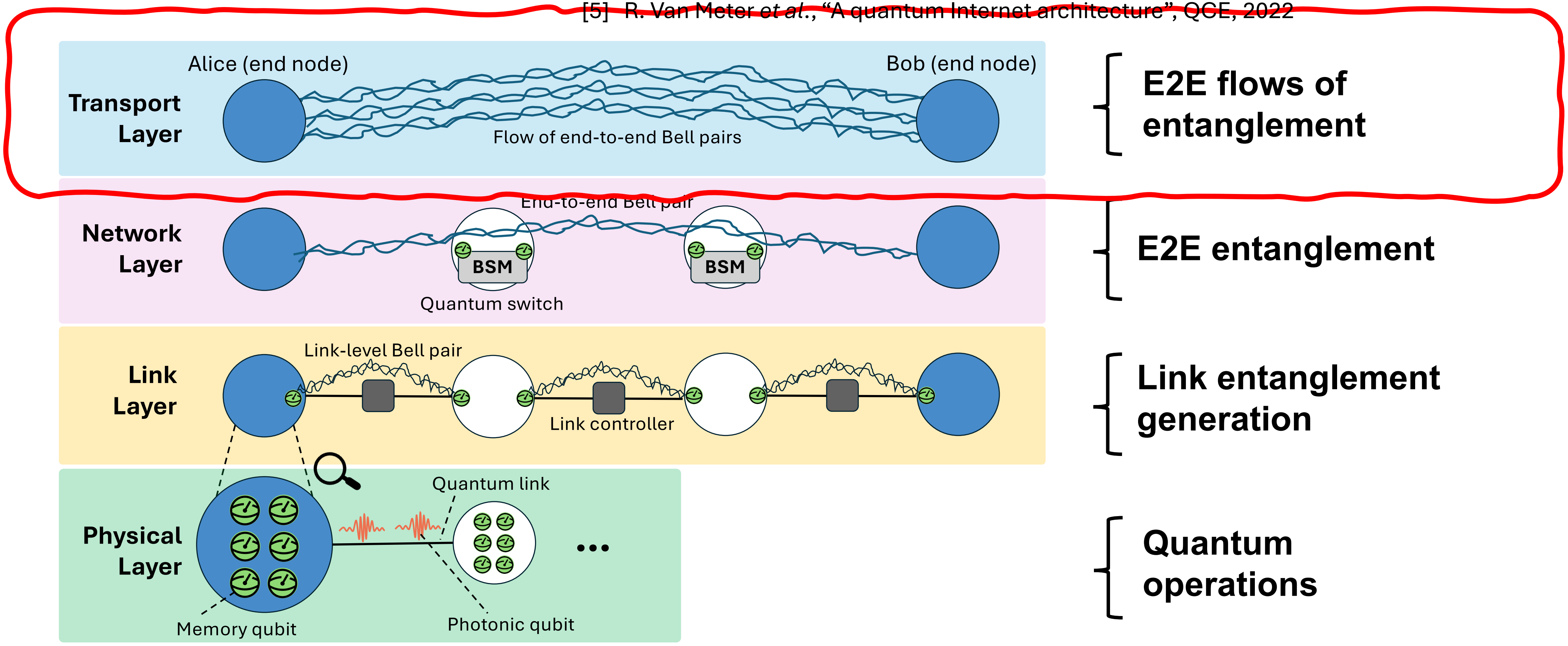

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Transport Layer: Quantum TCP

- As proof of concept, we employ a **TCP-like protocol**
- Quantum TCP manages quantum decoherence via AIMD congestion control
- Compare against AQTP [6] : Baseline based on memory reservation

[6] Zhao *et al.*, "An Asynchronous Transport Protocol for Quantum Data Networks," IEEE JSAC, 2024

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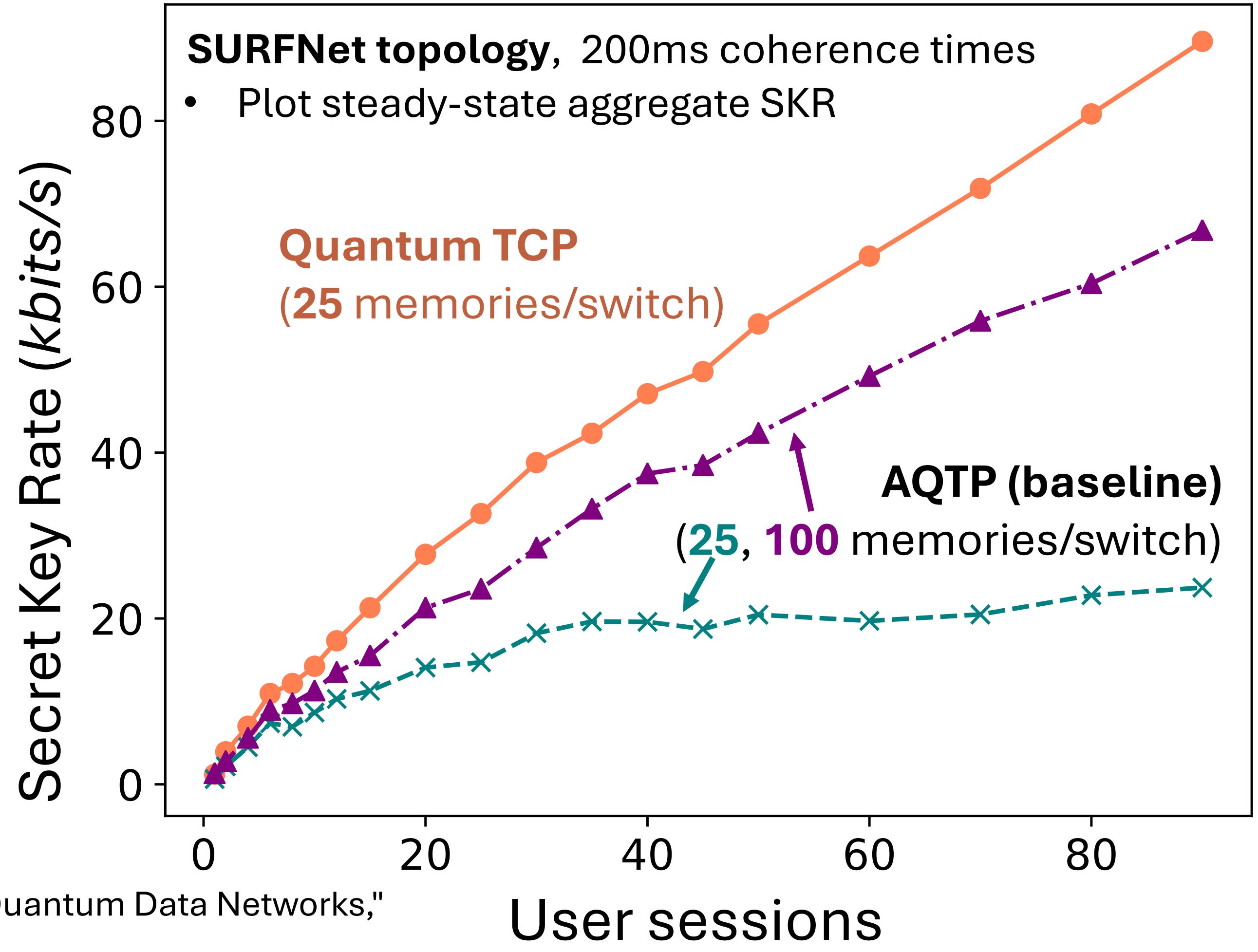

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Transport Layer: QPrimalDual

- Let's now replace Quantum TCP with a **quantum-informed** protocol

- Exploiting, for example, the trade off between generation rate and quality of entanglement

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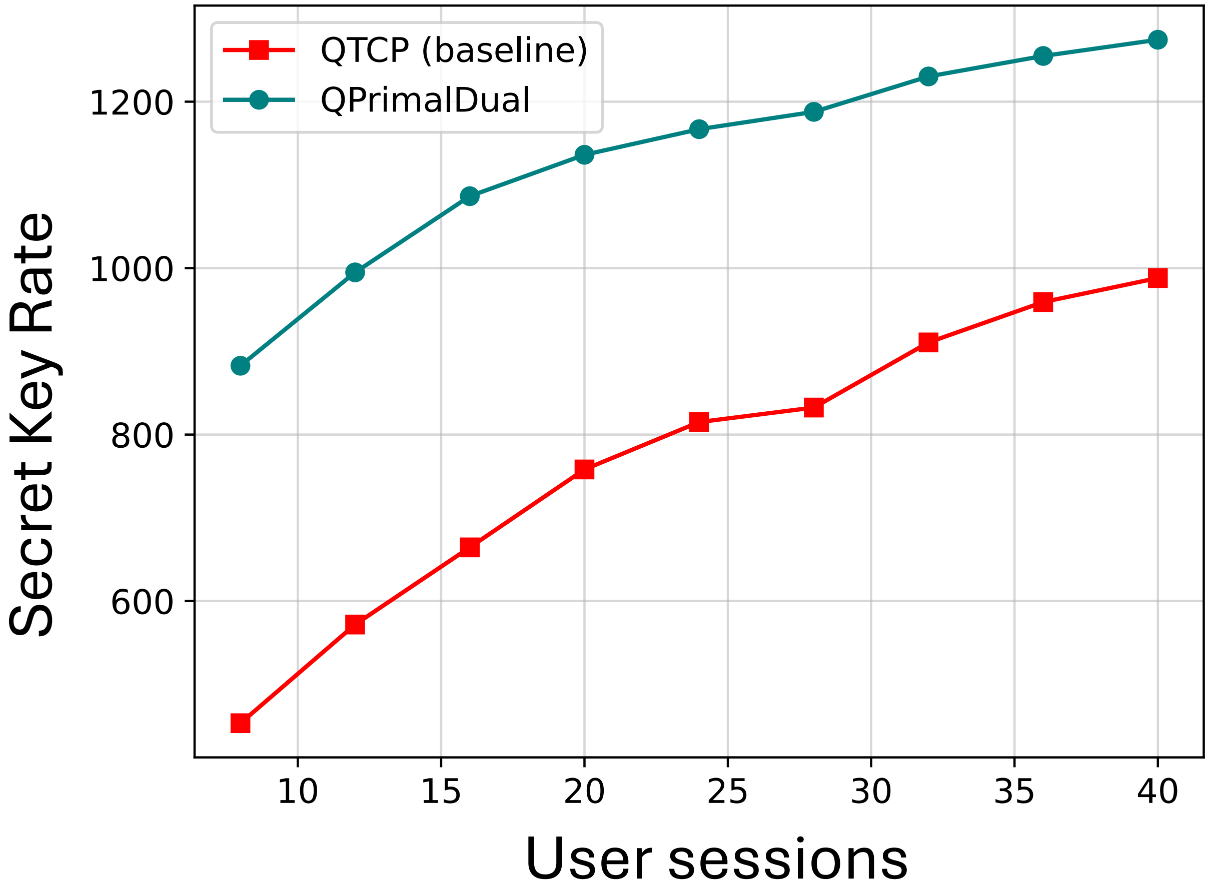

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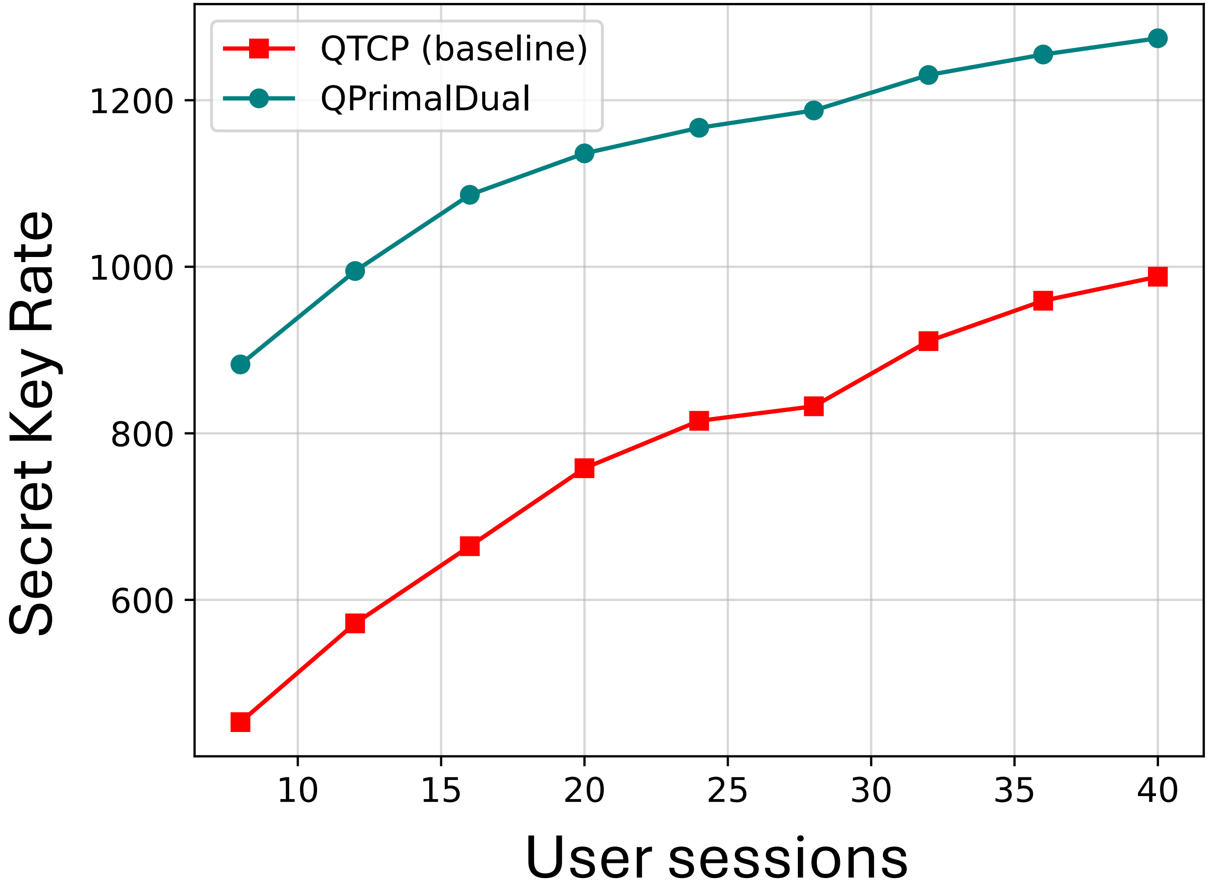
Transport Layer: QPrimalDual

- Let’s now replace Quantum TCP with a **quantum-informed** protocol

- Exploiting, for example, the trade off between generation rate and quality of entanglement

✓ **QPrimalDual** is scalable, decentralized, and provably stable. You can find details in our paper

NSFNet topology



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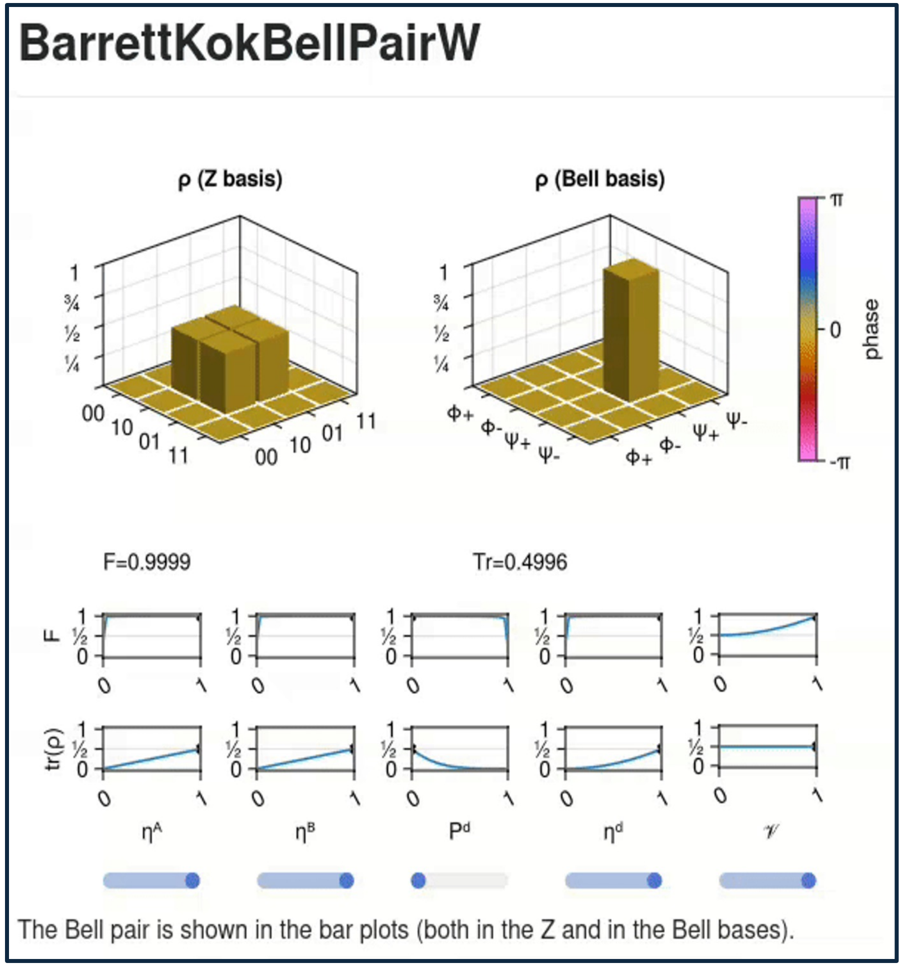
QuantumSavory



- Open-source simulator
- Highly modular
- QTCP already implemented
- Office hours Fridays 12:30pm EST

https://github.com/QuantumSavory