Quantum Internet

Axel Dahlberg

Entanglement for everyone

Enabling quantum communication between local quantum processors anywhere on earth.

Why construct a quantum internet?

For Quantum Communication

- Quantum secure communications
- Secure Identification
- Clock synchronization
- Protocols for distributed systems
- Combining telescopes
- Testing Physics
- Exponential savings in communication
- Cheating online games ☺
- ….

For Quantum Computation

- Linking small quantum computers
- Access the quantum “mainframe”

Stephanie Wehner (RL)

David Elkouss

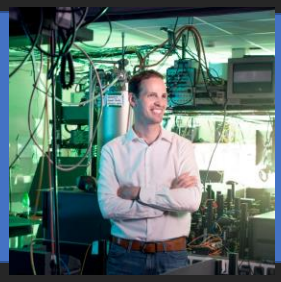
Applications

Network Stack

Quantum Repeater Schemes

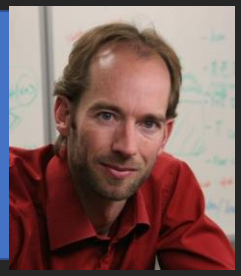
Processor Nodes

Tim Taminiau



Repeaters

Ronald Hanson



Erwin van Zwet

Wolfgang Tittel

Fab & Materials

Takashi Yamamoto

Nick de Jong

Optics Engineering

Anna Tschebotareva

Dirk Voigt

Software Engineering

Julio de Oliveira Filho

Rob Knegjens

Systems Engineer

Project Manager

Sander Kossen

Device Physics

Slava Dobrovitski

~ 8 Engineers (part time/full time)

~ 25 PhD Students/Postdocs

Judith de Keijzer

QuTech led Quantum Internet Alliance

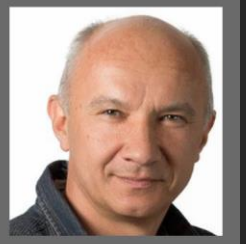
http://quantum-internet.team

GEORGE SADOWSKY

Board of ICANN, Internet Hall of Fame

DANIEL KARRENBERG

Founder of RIPE NCC, Internet Hall of Fame

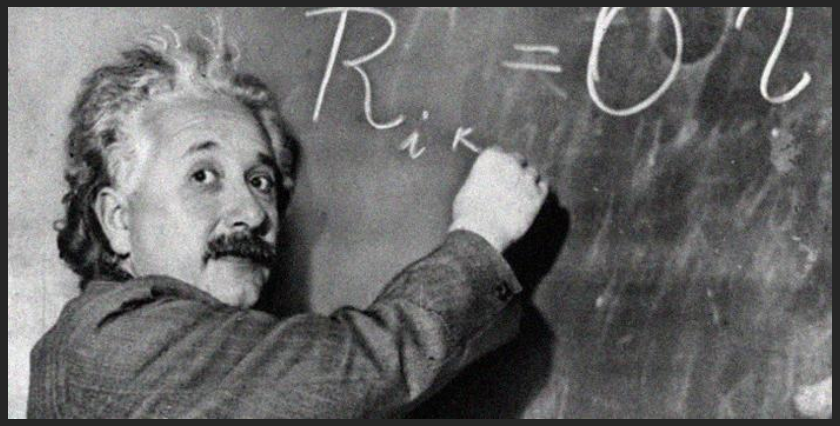


ARTUR EKERT

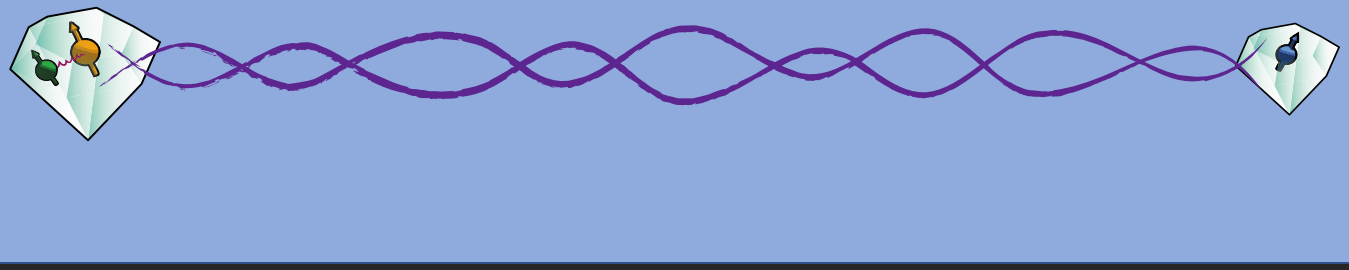
Inventor of Quantum Cryptography based on Entanglement

Entanglement

"Spooky action at a distance"



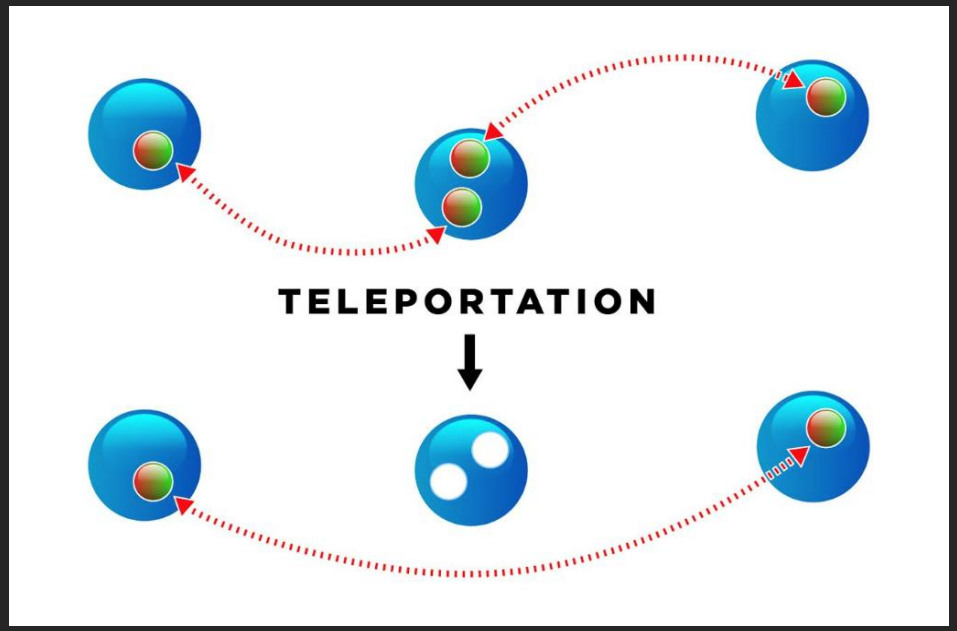
Entanglement



Properties of entanglement:

- Complete coordination: Measurement outcomes are random but perfectly correlated.
- Inherently private: No one can have any share of the entanglement.

Quantum repeater – bridging long distances



What needs to be done?

End Node

End Node

End Node

Repeater

Switch

Repeater

End Node

Classical Control Traffic

Switch

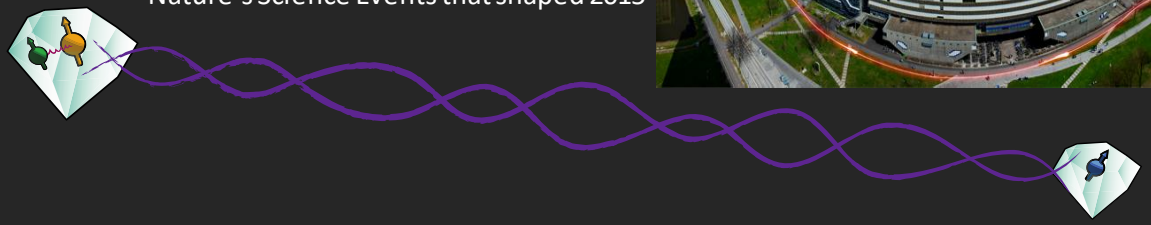
End Node

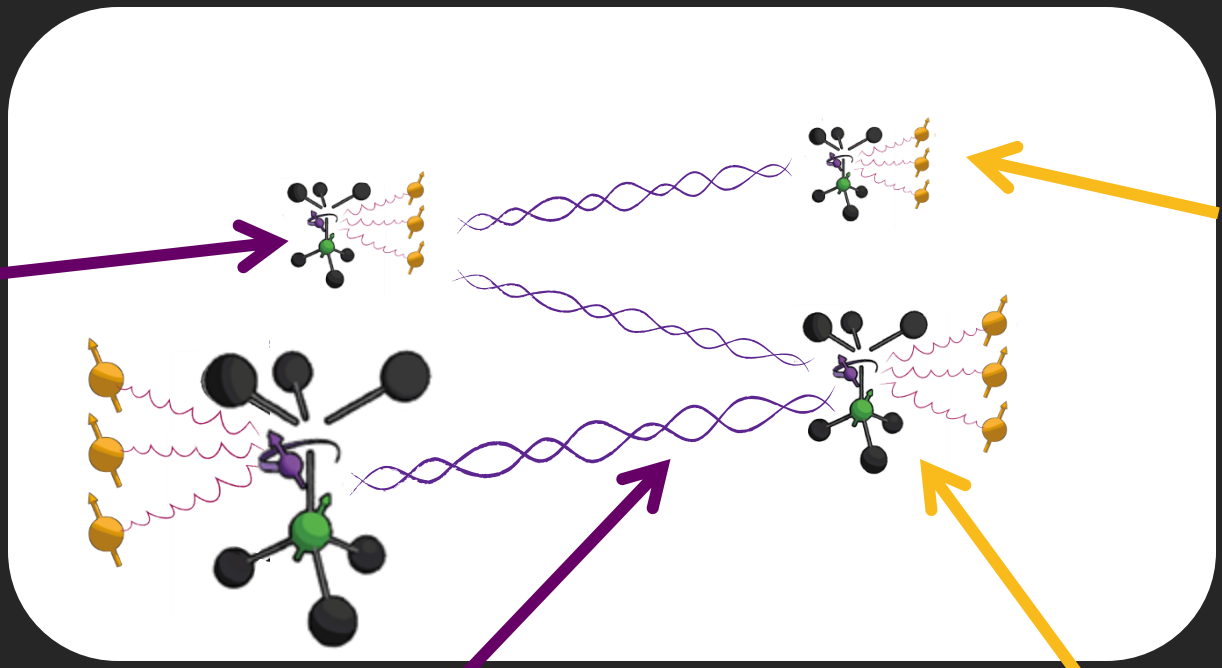
Prepare/Measure Qubits
Store Qubits
Manipulate Qubits
Noisy vs. “Fault tolerant”

Bridge long distances

End Node

First loophole free Bell test
Nature, 526, 682-686 (2015)
Science's Top 10 Breakthroughs of 2015
Nature's Science Events that shaped 2015



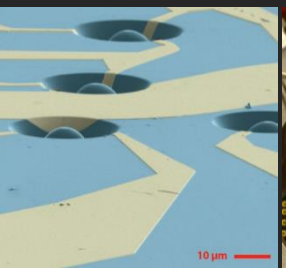


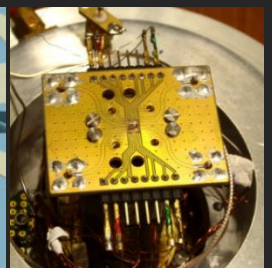
Communication qubits to generate remote entanglement (faster than 1/storage time)

Robust memory qubits for storage (also during networking activity!)

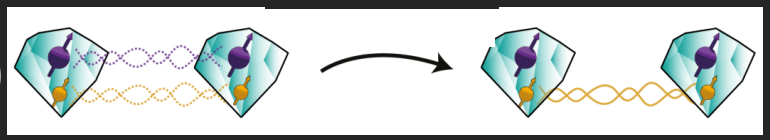
To bridge long distances: photons at telecom wavelength and/or free-space links to satellites

High-fidelity control and readout for processing and error correction



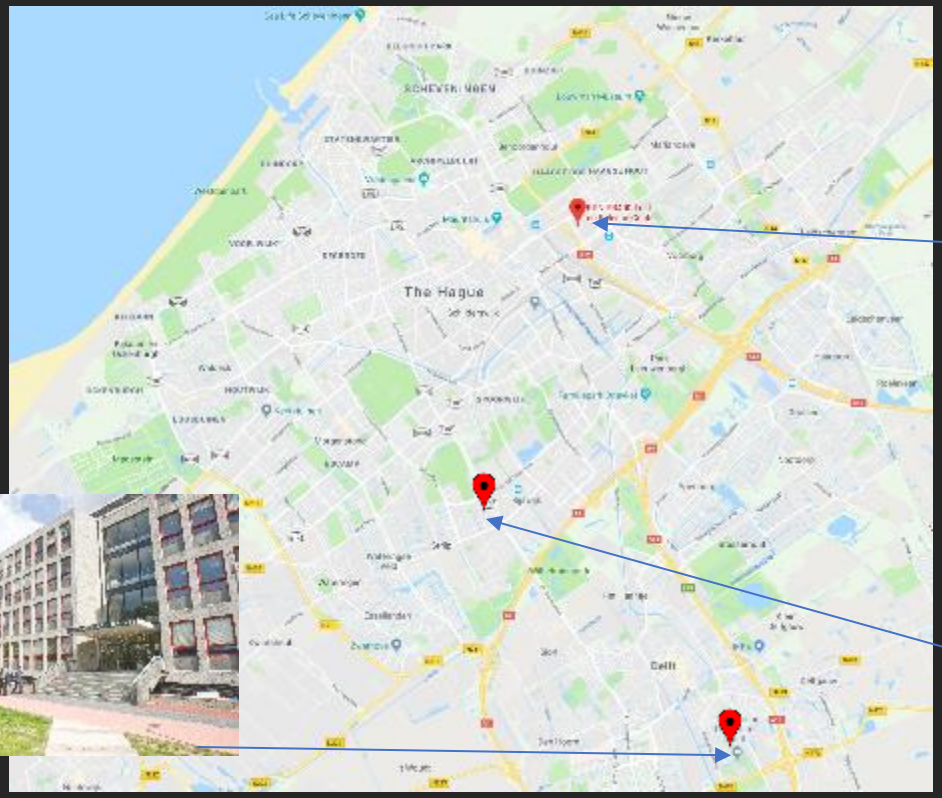


Repeater



Science 356, 928 (2017)

2019 Test link



KPN PB400: node location

TU Delft:
node location

KPN telephone exchange:
detector location

- Make 2 processor nodes that are prepared for future upgrades
- Direct Quantum Key Distribution link authenticating traffic
- Make use of existing telecom (dark) fibers
- Generation of entanglement between the 2 nodes
- Gain experience

2020 Demo

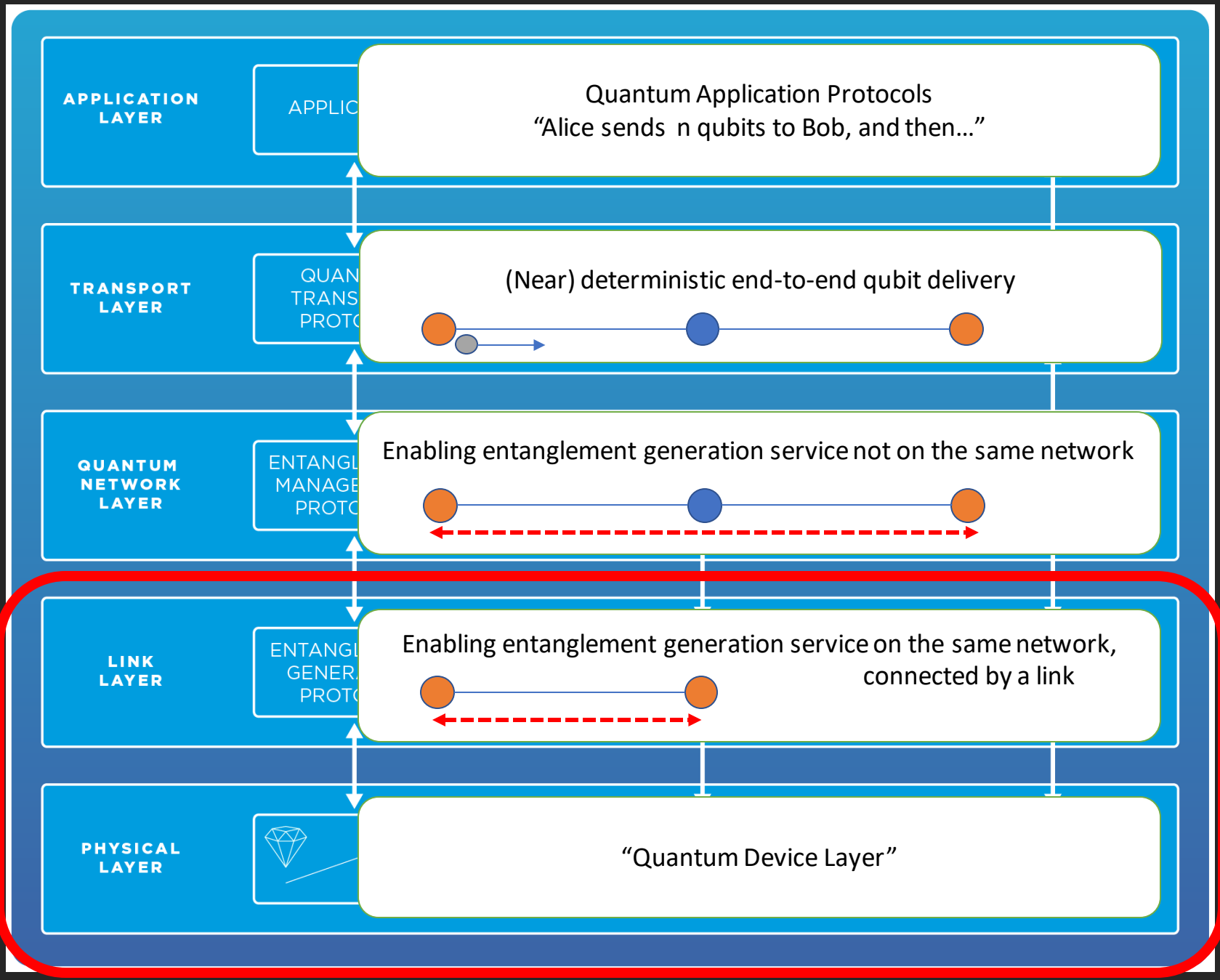
- Upgrade existing nodes
- 4 processor nodes
- Direct QKD links between neighbouring nodes to authenticate control traffic
- Demonstrate first quantum network stack
- Universal programmability
- Make platform available on the internet

RIPE NCC
RIPE NETWORK COORDINATION CENTRE

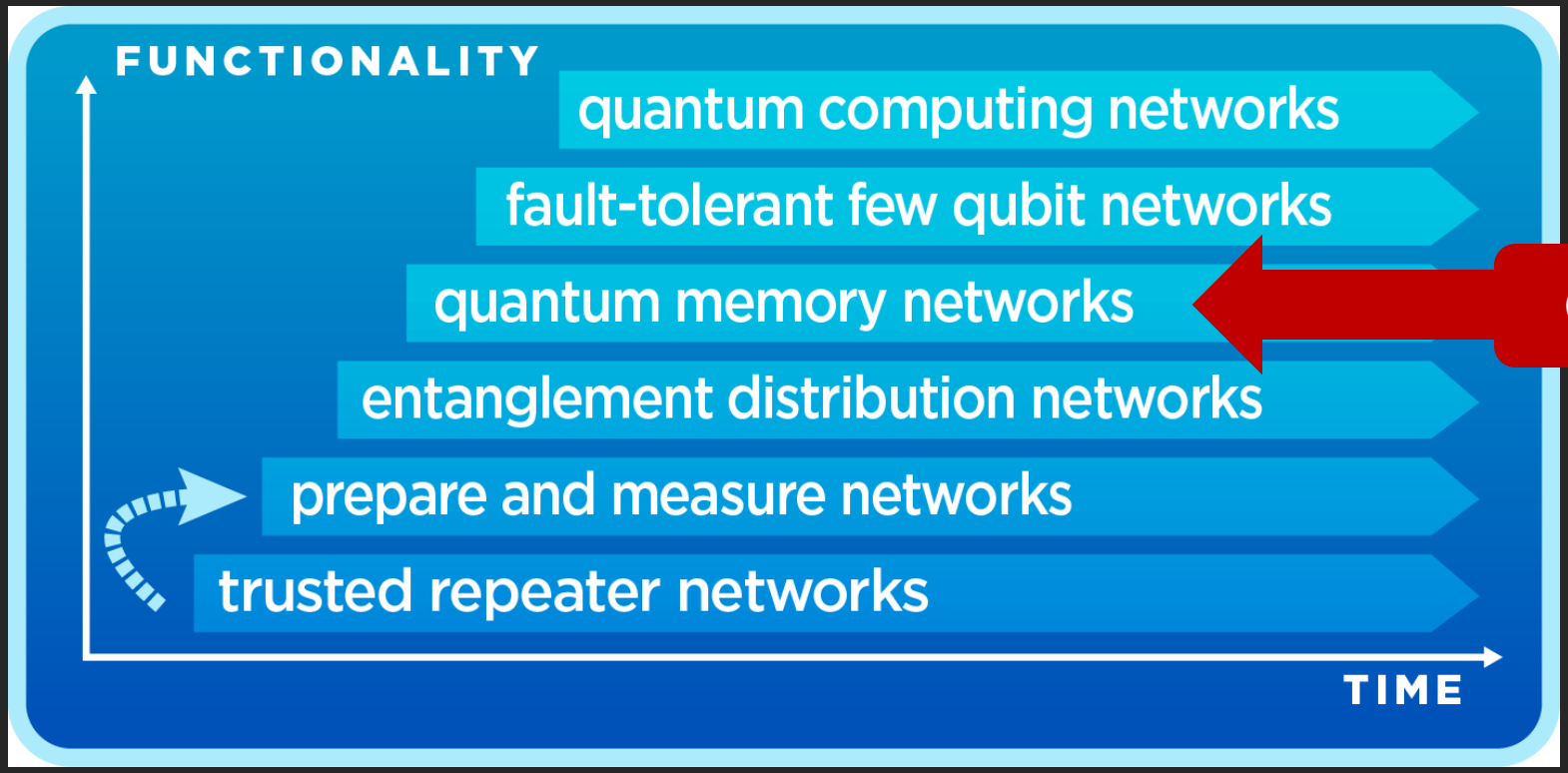
amsix
amsterdam internet exchange

SURF NET

kpn

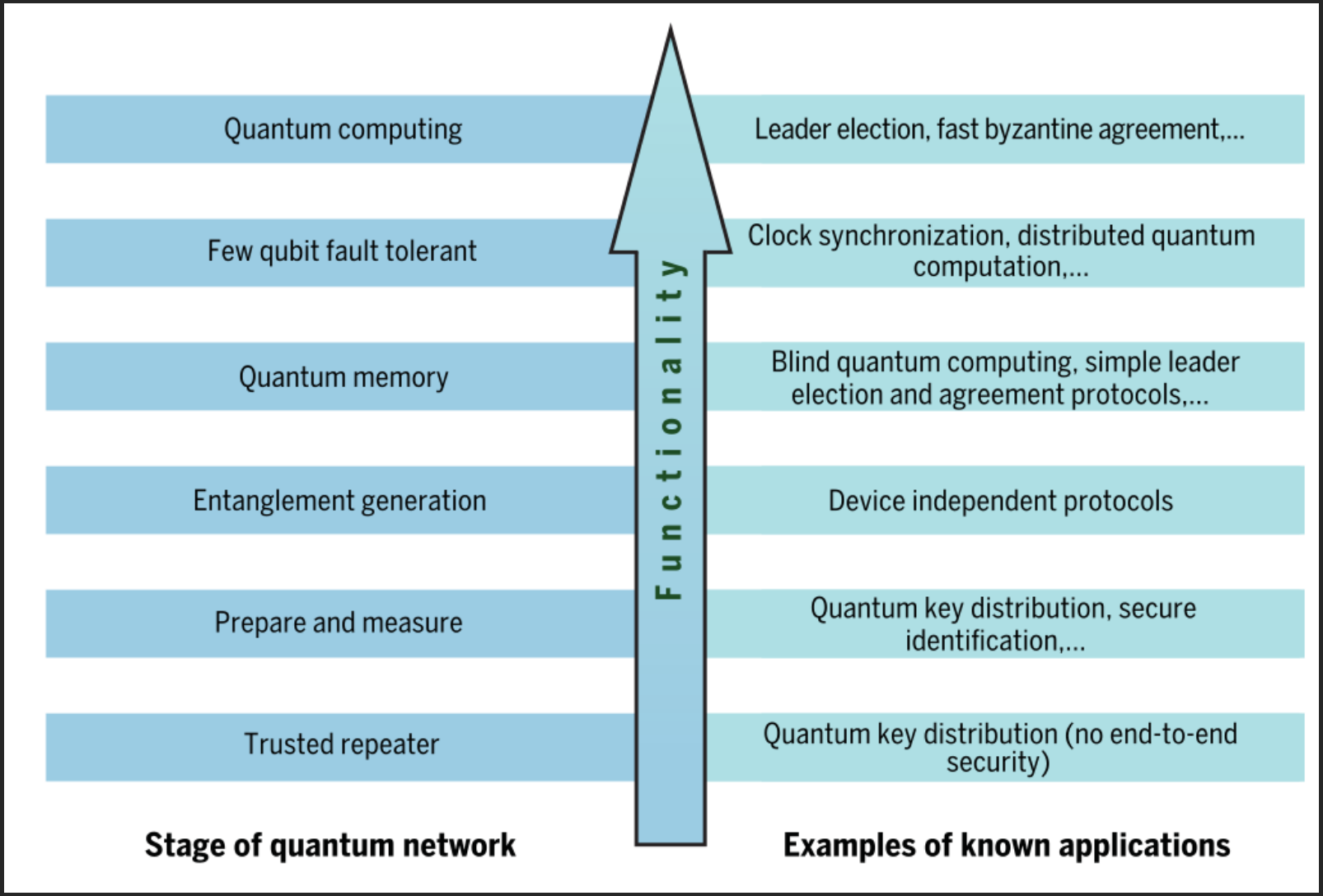

APPLICATION LAYER
APPLIC
Quantum Application Protocols
“Alice sends n qubits to Bob, and then…”
TRANSPORT LAYER
QUAN
TRANS
PROTO
(Near) deterministic end-to-end qubit delivery
QUANTUM NETWORK LAYER
ENTANGL
MANAGE
PROTO
Enabling entanglement generation service not on the same network
LINK LAYER
ENTANGL
GENER
PROTO
Enabling entanglement generation service on the same network, connected by a link
PHYSICAL LAYER
“Quantum Device Layer”

Application centric stages of network development



S. Wehner, D. Elkouss, R. Hanson – Science – 6 Nov 2018

Application centric stages of network development



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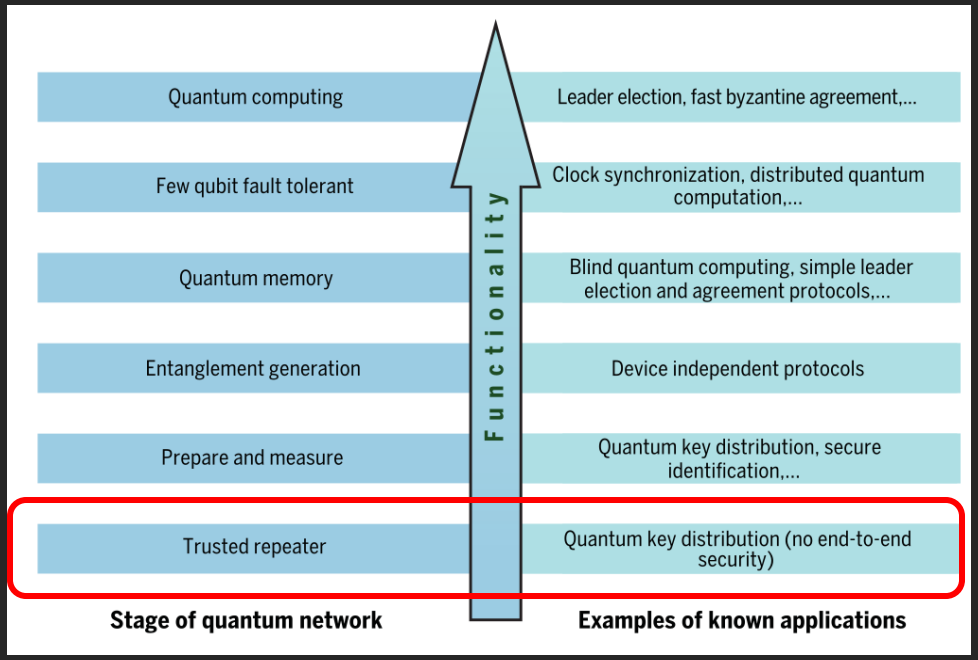

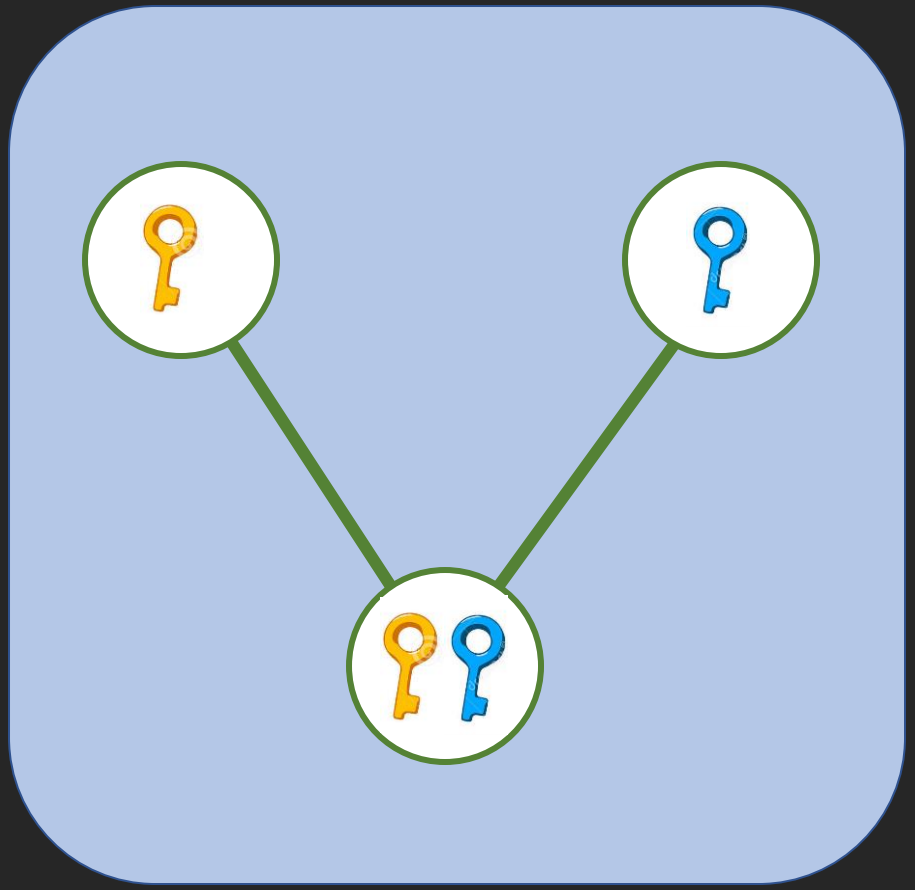

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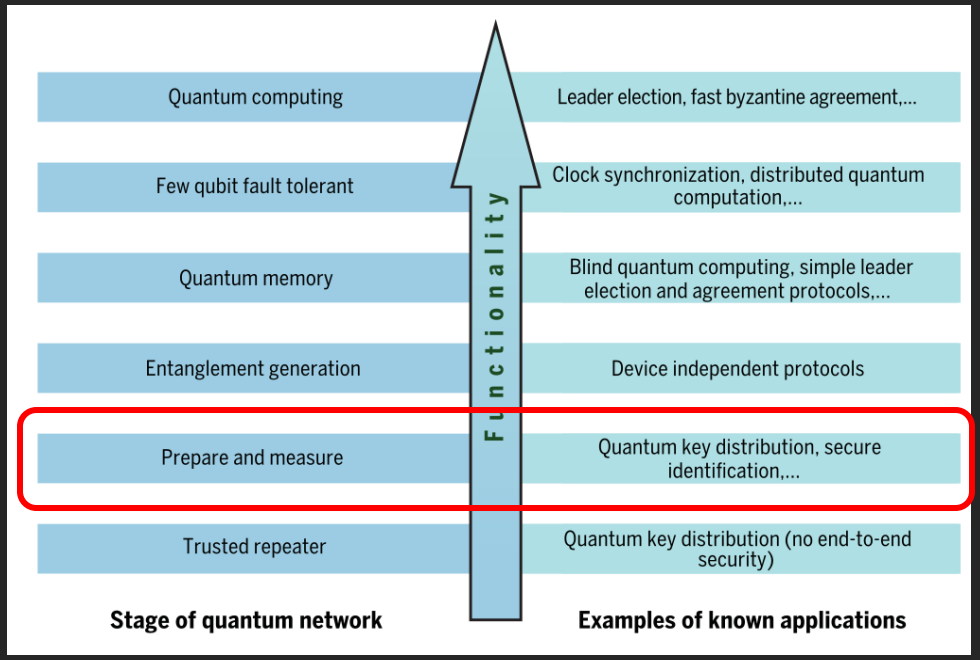
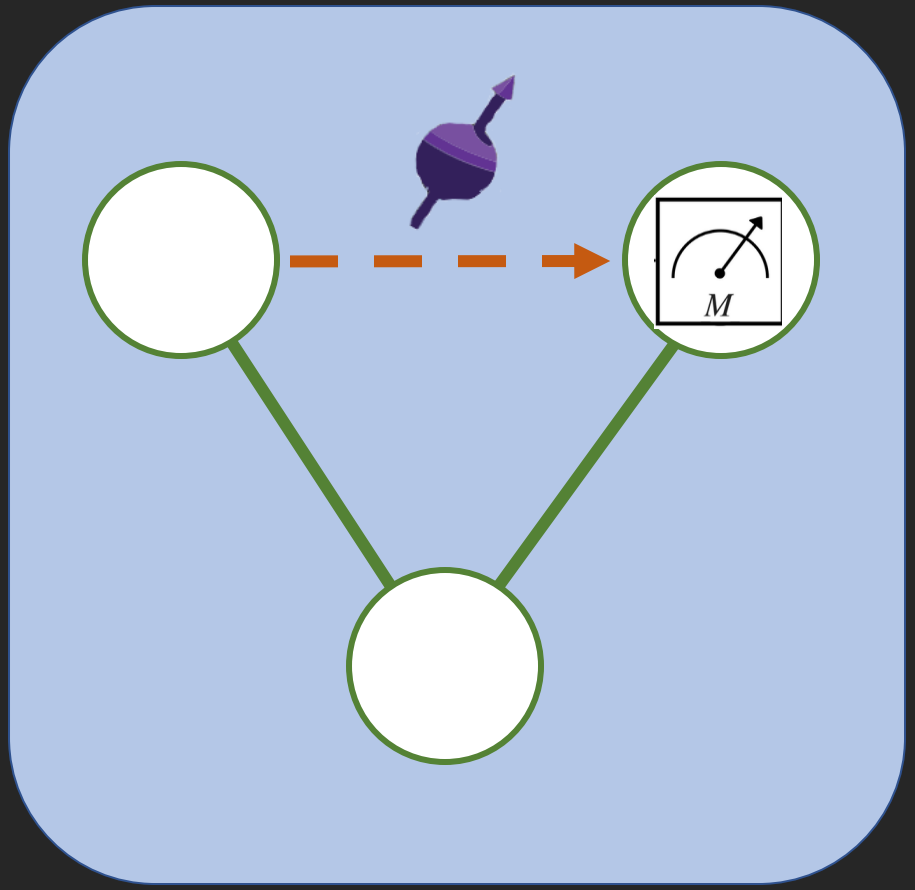
Application centric stages of network development





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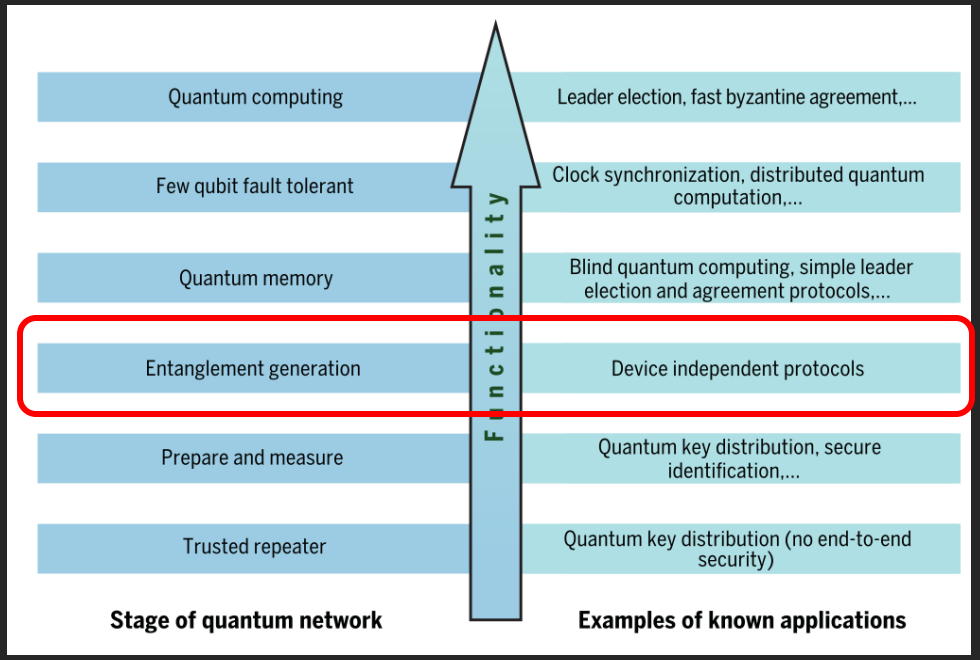

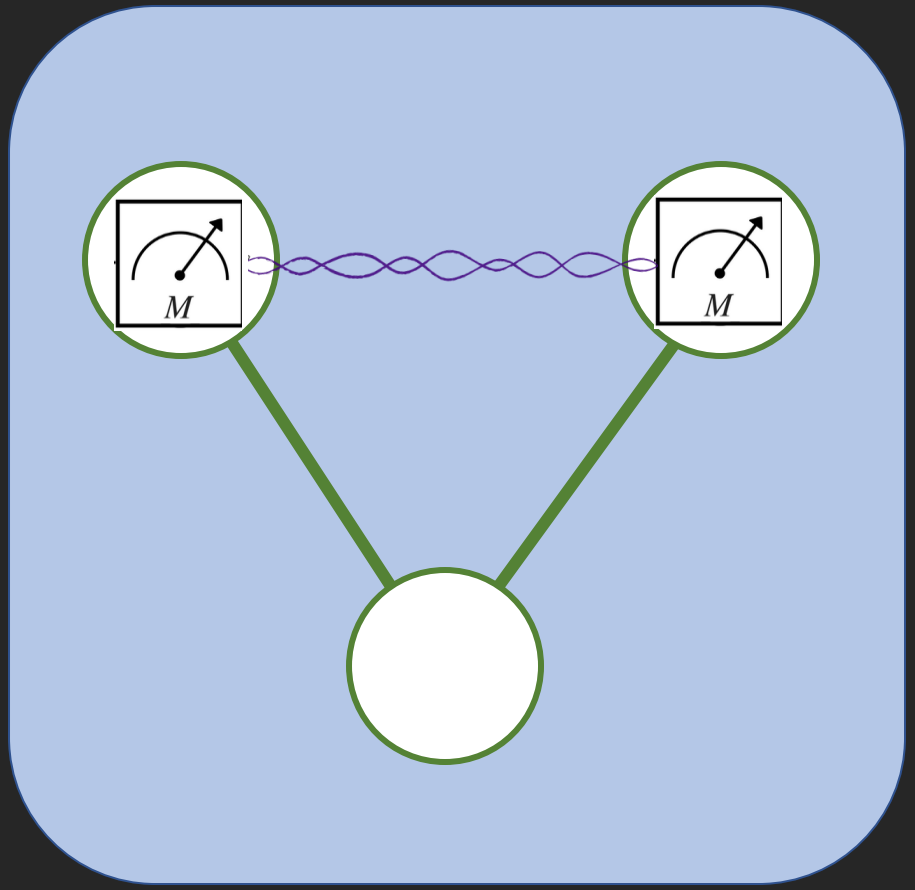

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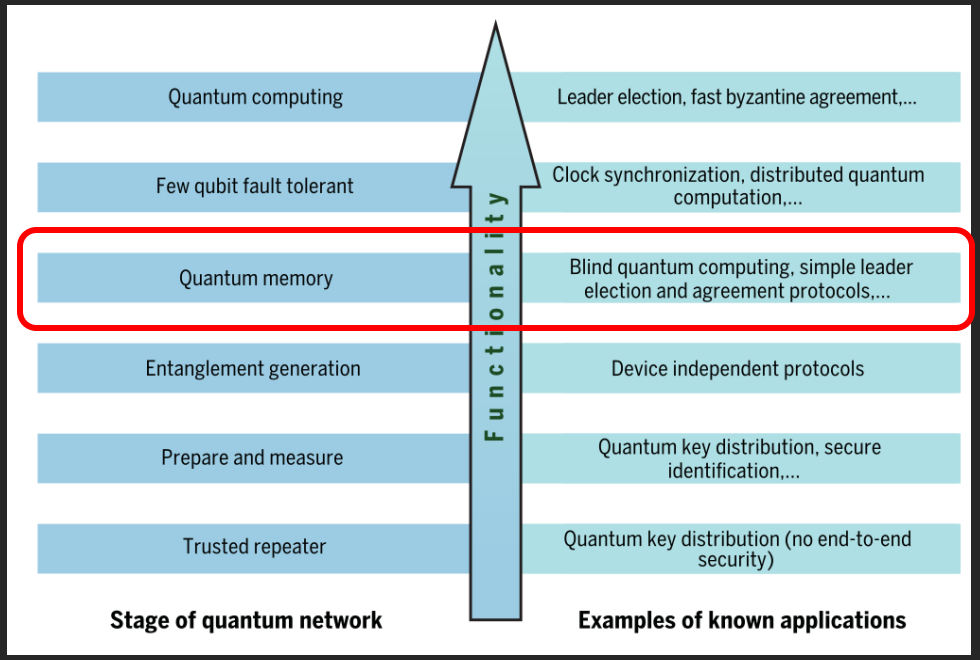

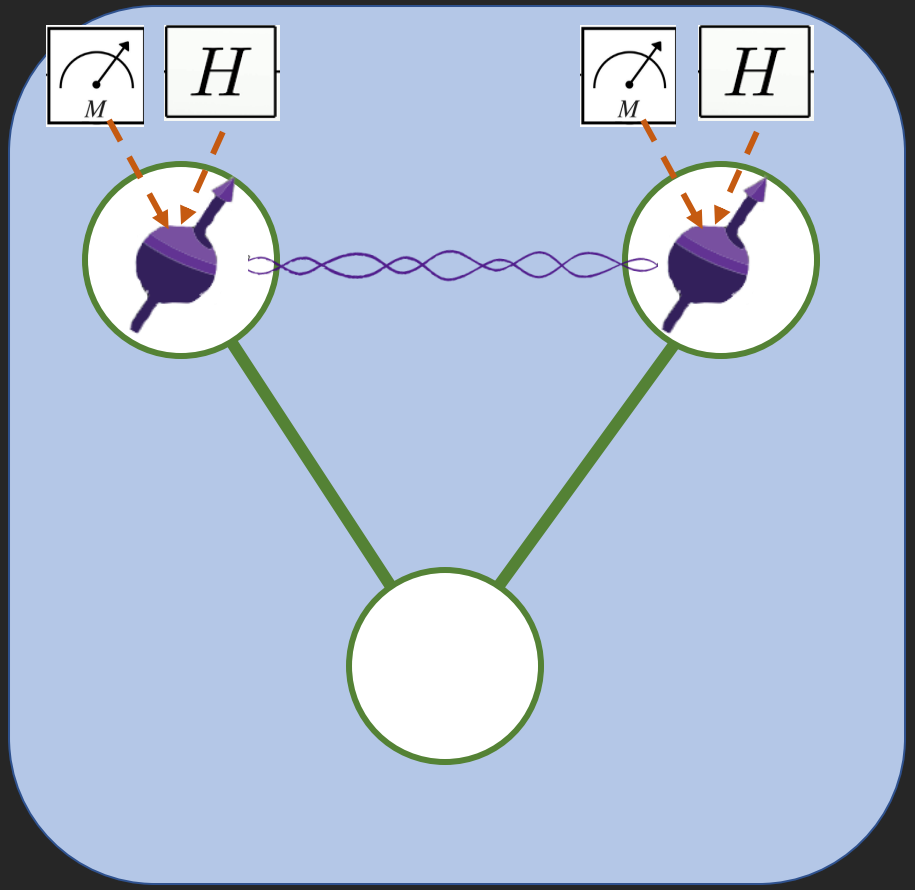

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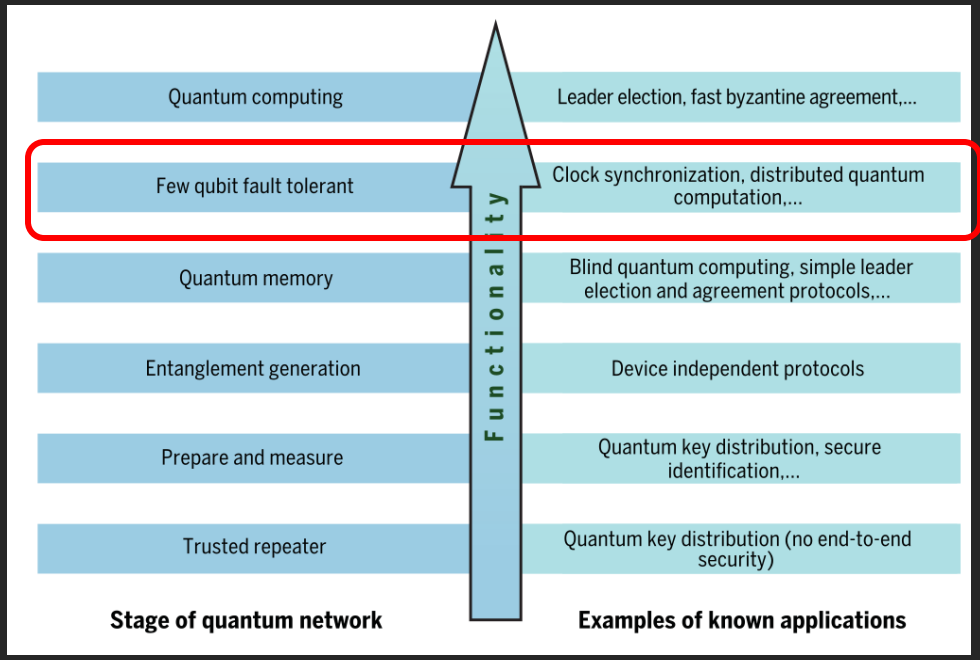

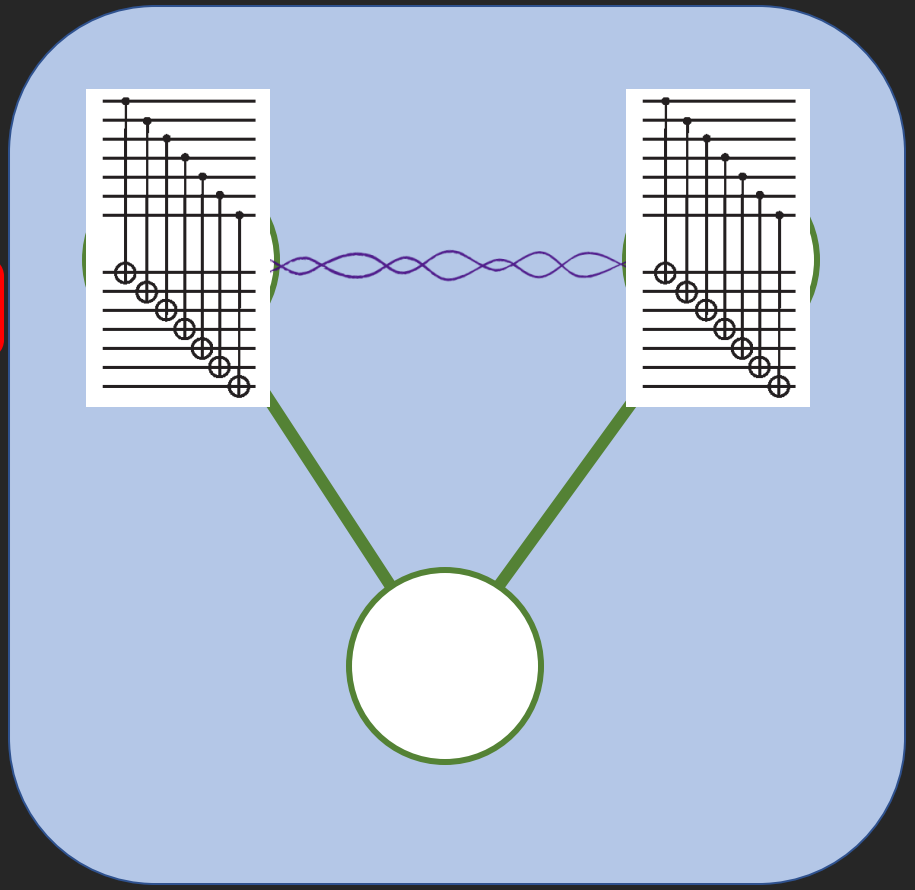

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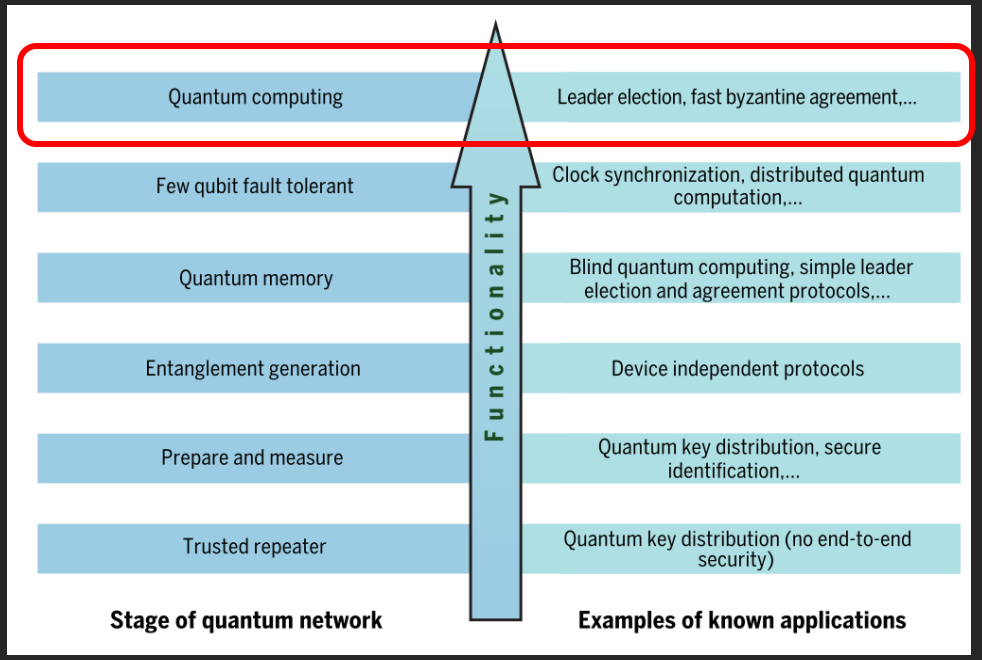
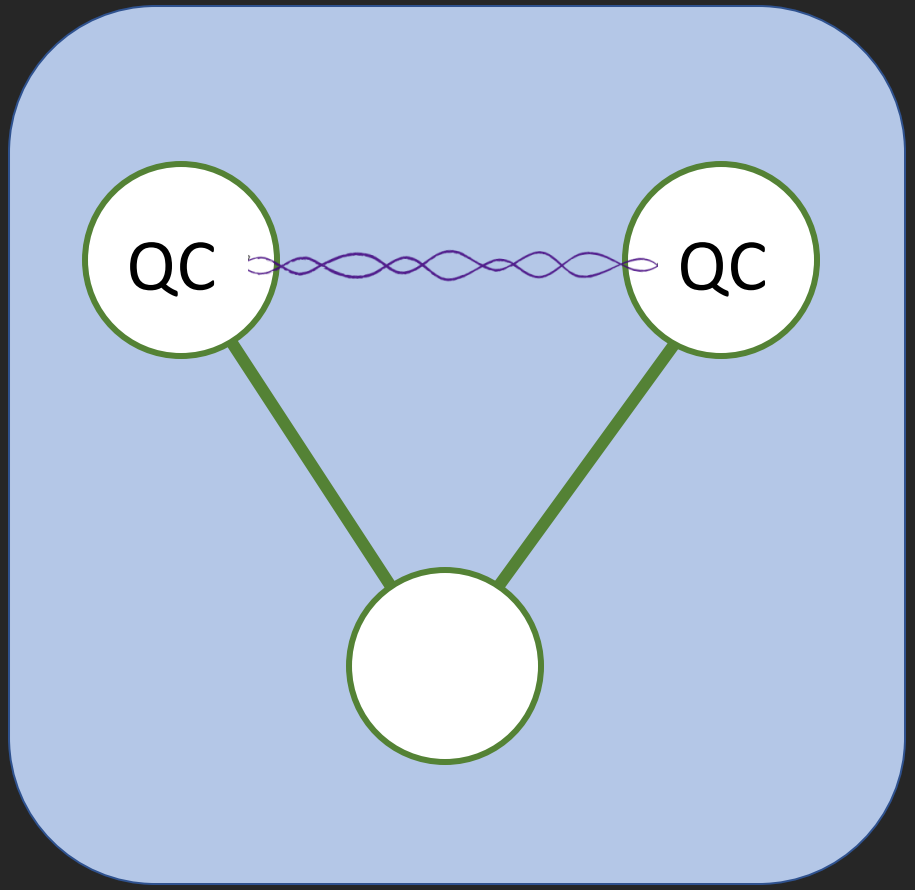
Application centric stages of network development





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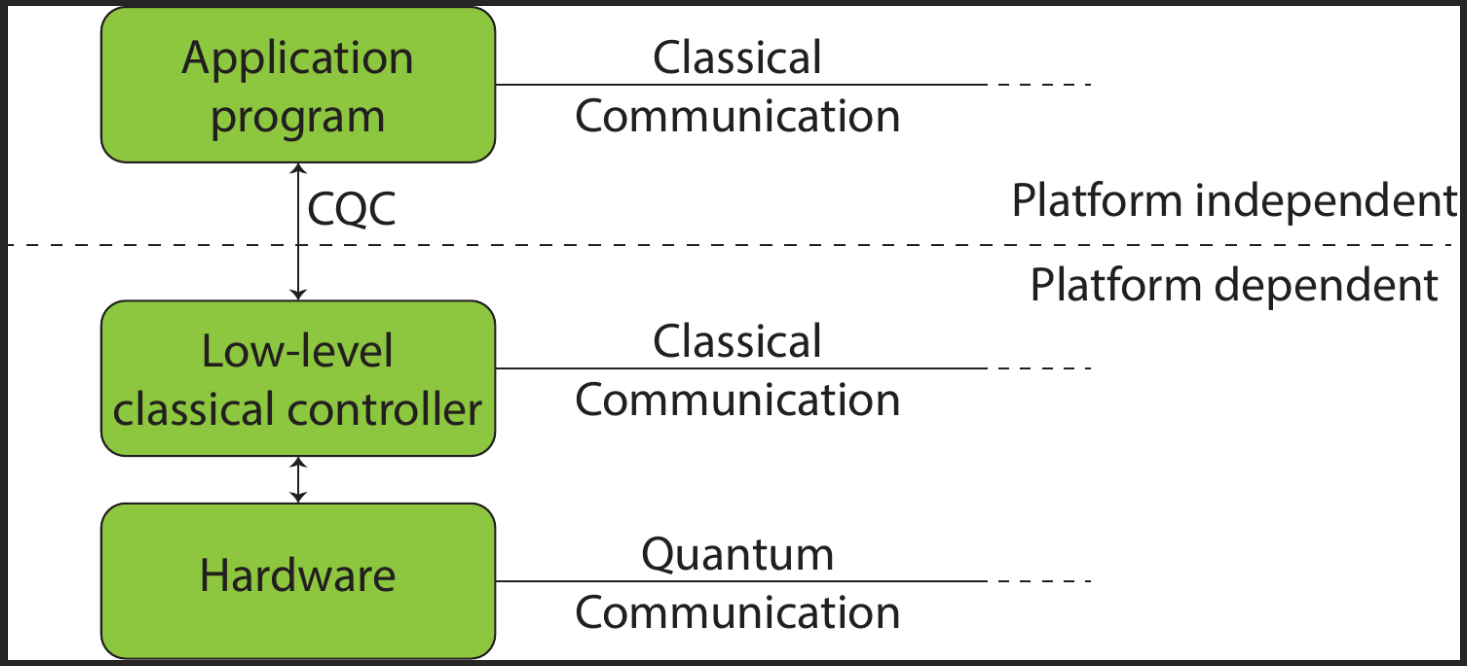
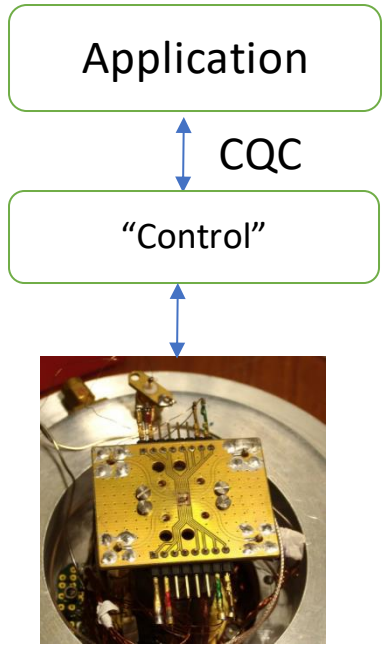
Questions? :)

Programming a quantum network



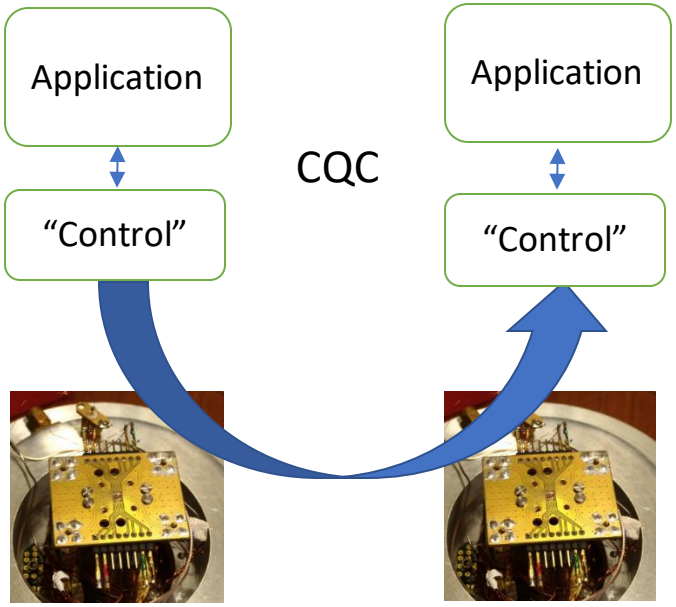
Software Stack



Interacting with local quantum device

Executing operations, measurements, ….

Network Stack



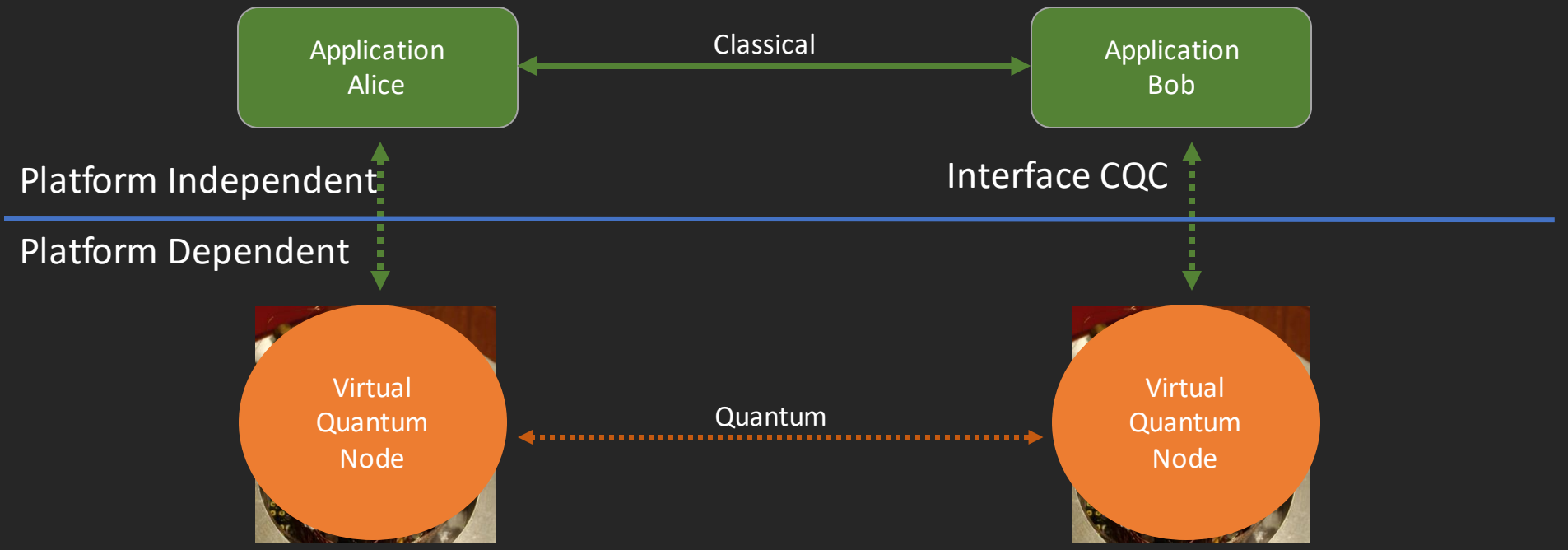
Interacting with remote quantum device

Sending + receiving qubits

Generating entanglement

Quantum Network Software

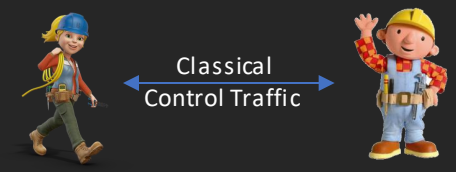
Don’t have your own hardware? ☺



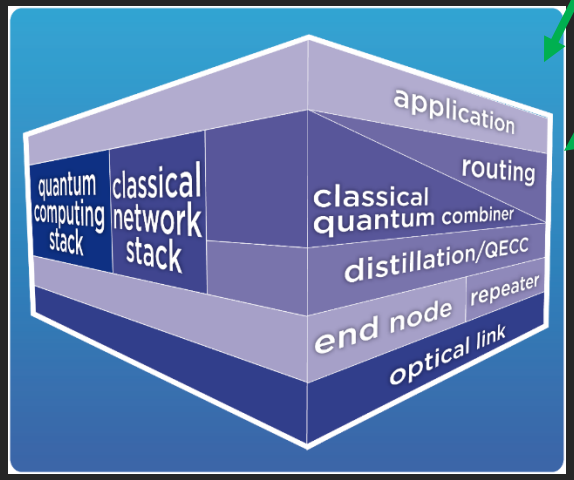
SimulaQron – http://www.simulaqron.org
QuTech – KPN Programming Competition !

RIPE NCC
RIPE NETWORK COORDINATION CENTRE

Hackathon, 13+14 October 2018
http://quantum-internet.team

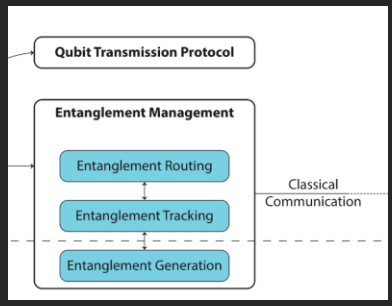


Design of few qubit protocols
Analysis against noise and general errors



Routing protocols

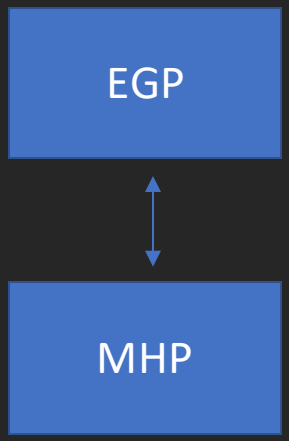
Universal programmability
- Quantum Network Stack
- "QNodeOS"



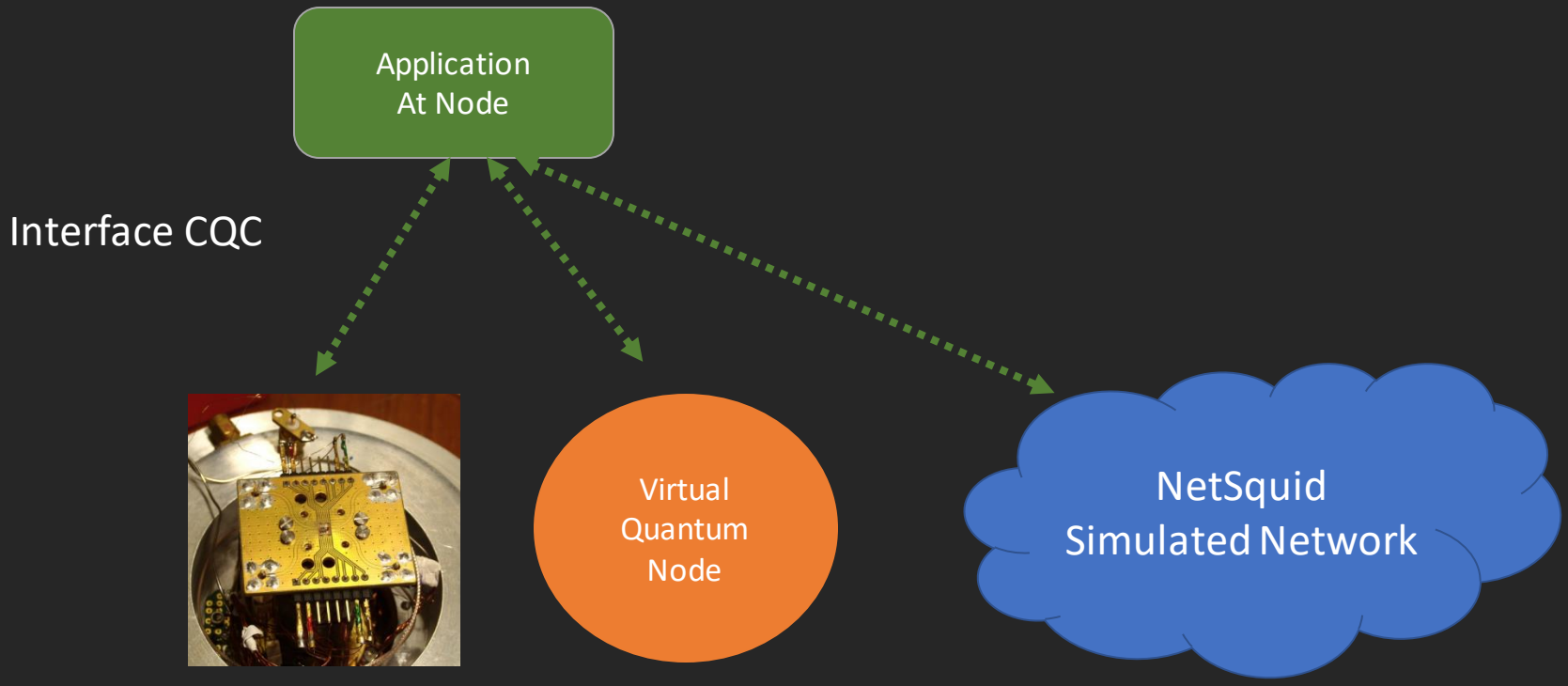
SimulaQron
Application level simulator for software development
http://www.simulaqron.org

NetSquid: Low level Network Simulator for
Quantum Information using Discrete events.

What's where?



Link Layer – Entanglement Generation Protocol
Decisions and higher level logic

Physical Layer – Midpoint Heralding Protocol
Timing synchronization
Automated except: On/Off

Network emulation