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”
QuTech led Quantum Internet Alliance
http://quantum-internet.team
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?

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

Bridge long distances

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

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

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

End Node

Science’s Top 10 Breakthroughs of 2015
Nature’s Science Events that shaped 2015

Repeater

Science 356, 928 (2017)
2019 Test link

- 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
Quantum Application Protocols
“Alice sends $n$ qubits to Bob, and then…”

(Near) deterministic end-to-end qubit delivery

Enabling entanglement generation service not on the same network

Enabling entanglement generation service on the same network, connected by a link

“Quantum Device Layer”
Application centric stages of network development

- Quantum computing networks
- Fault-tolerant few qubit networks
- Quantum memory networks
- Entanglement distribution networks
- Prepare and measure networks
- Trusted repeater networks

QINC 2020

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Application centric stages of network development

- Quantum computing
- Few qubit fault tolerant
- Quantum memory
- Entanglement generation
- Prepare and measure
- Trusted repeater

Functionality

- Leader election, fast byzantine agreement, ...
- Clock synchronization, distributed quantum computation, ...
- Blind quantum computing, simple leader election and agreement protocols, ...
- Device independent protocols
- Quantum key distribution, secure identification, ...
- Quantum key distribution (no end-to-end security)

Stage of quantum network

Examples of known applications

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Examples of known applications
- Quantum key distribution (no end-to-end security)
- Quantum key distribution, secure identification,....
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- Quantum memory
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- Quantum computing

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Questions? :)
Programming a quantum network
Quantum Network Software

**Software Stack**

- Application
- CQC
- "Control"

Interacting with local quantum device
Executing operations, measurements, ...

**Network Stack**

- Application
- CQC
- "Control"

Interacting with remote quantum device
Sending + receiving qubits
Generating entanglement

Quantum Network Software
Don’t have your own hardware? 😊

Simulation

Application Alice

Classical

Application Bob

Platform Independent

Virtual Quantum Node

Interface CQC

Platform Dependent

Virtual Quantum Node

Quantum

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

RIPE NCC

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?

EGP

Link Layer – Entanglement Generation Protocol
Decisions and higher level logic

MHP

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

Application
At Node

Interface CQC

Virtual Quantum Node

NetSquid Simulated Network