Summary of Key Concepts

Quantum Networking

Week of March 24th, 2024

Resources

- QXQ YLC Week 21 Lab [STUDENT].ipynb
- **NOTE**: Homework is just on Canvas this week, there is no notebook.
- [QuTech: Quantum Network Explorer]()

Key Terms

Key Term	Definition
Quantum Network	A system in which quantum processors can communicate with each other.
End Node	A quantum processor (computer) connected within a network.
Communication Line (Channel)	A quantum channel connecting end nodes in a network.
Quantum Repeater	A general term for any device that connects multiple quantum communication lines, resulting in a larger overall network.
Entanglement Swapping	A quantum protocol that allows entanglement to be swapped between 2 out of 3 parties (ex: Alice, a repeater, and Bob).
Entanglement Distillation (Purification)	A protocol that uses many weakly entangled qubits to “distill” one highly entangled pair of qubits.

Lecture

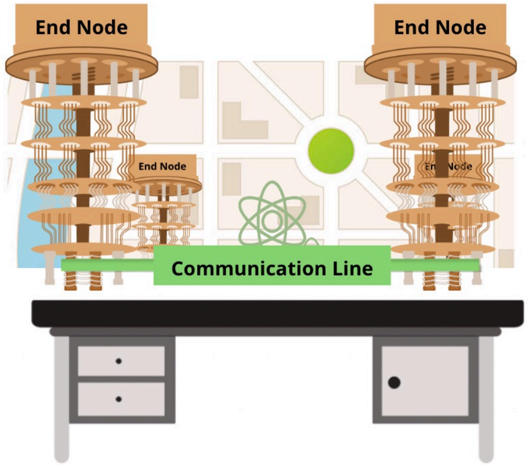
Learning Objectives

1. Recognize what a quantum network is.
2. Recognize what an end node, communication line, and quantum repeater are.
3. Recognize the entanglement swapping protocol.
4. Recognize the current state of quantum networking from a technological and policy perspective.

Key Ideas

1. Quantum processors (ex: quantum computers) can communicate with each other in the following ways in order to implement a **quantum network**:
    a. **Distributed Quantum Computing & Sensing**: Many quantum computers work together to solve a problem or increase sensing abilities.
    b. **Quantum Internet**: Using the inherent quantum interconnections, this could allow for a highly secure quantum & classical internet with QKD built into every-day communications.

2. The structure of a quantum network consists of **end nodes** (quantum processors) and quantum channels. **Quantum channels** serve as the connecting link between end nodes also known as communication lines.

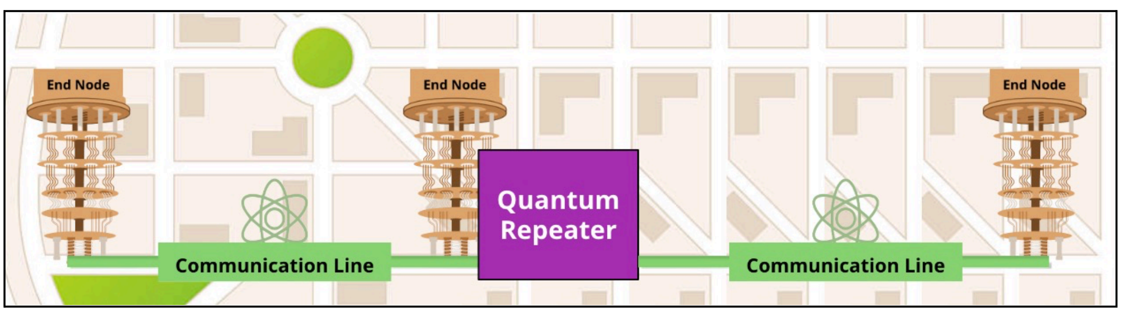


In order to allow quantum processors to communicate with each other through these quantum channels, **quantum protocols** must be used. Importantly, it is possible to implement these protocols with only 1-2 qubits at a time. This means that we already have the quantum processors necessary to build a quantum network!

a. Protocols in a quantum network include:
   - Quantum teleportation: send a quantum state without physically sending qubits
   - Entanglement swapping: double the maximum distance over which entanglement can be shared.

Quantum Protocols:	**Quantum Key Distribution**	**Quantum Teleportation**	**Superdense Coding**
Minimum Number of Qubits Required:	**1**	**2**	**2**

However, we are still limited by **noise** — the longer a qubit spends on a communication line, the more exposed to noise it becomes. **Quantum Repeaters** provide a solution which connect multiple communication lines and allows us to build a quantum network as large as we want.



3. **Hardware for a Quantum Network:** Using the potential hardware for each of the key components of a quantum network is also a critical area in this field.
   a. **End Node Hardware**: quantum processors being used within a network. This includes photons, NV centers (defects in diamond), and ion traps.
   b. **Communication Line Hardware**: physical form of qubit does not need to be the same as the qubit at the end nodes. This allows for more flexible options

however photons are currently the most likely candidate as it travels far in pre-existing/classical fiber optic networks.

c. **Quantum Repeater Hardware**: the least developed of the hardware. The questions that still need to be answered are:
    i. *Can end nodes work as quantum repeaters?*
    ii. *Should quantum repeater design inform end node & communication line design or the other way around?*
    iii. *Is it better to use 1 really good repeater or many mediocre repeaters?*
    iv. *Are there other better technologies to use as quantum repeaters?*

4. **Standards & Policies** are vital to determine a set of fair policies for creation and use of quantum networks. The primary **policies** being:
    a. Ensure building physical networks does not harm environments/communities.
    b. Not forced to use one company or technology that may not actually eb the best or freezes technological progress.
    c. Use of networks should not violate existing laws between countries.

Standards established by the ETSI & IEEE are being developed to establish common vocabulary, interfacing, and post-quantum cryptography. Policies are also being taken by many countries around the world, including (but certainly not limited to!):

a. **USA** - Developing initiatives such as NQI to improve quantum information science and NSA who work on both quantum & post-quantum cryptographic methods.
b. **China** - Made a 5 Year Science & Innovation Plan to achieve major breakthroughs by 2030.
c. **EU** - Identifying 4 main areas of quantum development: Communication, Computing, Simulation, and Sensing & Metrology.