- **Quantum Network Nodes**

  Step 0: Devices
  - **Quantum Memory: for networking applications (long hold time) – specify/quantify memories for networking application**
  - **More in slide 5**

  Step 1: Quantum Routing of entanglement: simple schemes without memory
  - Move functionality from labs to testbeds: start simple
  - Opto-mechanical systems to do routing with few dB losses
  - Target to provide entanglement services on schedule
  - Quantum-connect 3 or 4 nodes in non-trivial configuration (4-5 years)

  Step 2: Develop quantum repeater networks

  - Investigate both one-way and two-way quantum repeaters (bell measurements and switching)
  - Demonstrate repeater networks in type I and type II configurations
  - Test using memory assisted BB84, targeting to challenge direct transmission capacity (3-4 years)

  - Step 3: Adding Robustness, Entanglement purification and error correction **to the networks**
  - Perform switchable Bell measurements
  - Experiments with Greenberger–Horne–Zeilinger states
  - Schemes for quantum entanglement purification (6-10 years)
  - Teleported quantum gates

Quantum Network Operation and Control

Key step: Synchronize to classical information flowing in the network

- Uses concepts of management telemetry
- Use feedback from global network testing, or single links testing
- Investigate synchronization techniques from previous q-cryptography experiments
- Key question: how to expand the timing techniques to more complex operations?
- OSCAR systems from ESNet can be used to configure the higher communication levels
- Entanglement tracking protocols must be developed
- Add security to the classical channels by taking quantum into account

From Local Area Quantum Networks to Wide Area Quantum Networks

- Buying (renting) fiber pairs seems feasible
- Getting colocation space is a larger problem (certification, appropriate wavelenghts)
- Develop manpower to support the new nodes
- Easier to start with metropolitan-area networks where fiber is already available
- Key question: How to make the fiber providers accept first generation quantum gear?
- Use the resources and experience from the research and education community
- Hourglass model for the development of the quantum internet

- Choose technology that can be scaled and deployed
- Determine the quality of fiber
- Determine Maps, topologies and losses

- Coordination with spatial optical networks, satellite-based networks (AFRL, NASA)
- Indicate the benefits of coordination between different agencies

Additional thoughts

- Network nodes in unmanned substations - what are the requirements for equipment in terms of **remote operation and maintenance** to make such nodes sustainable to operate?

- What questions do we need to answer before we can send the first satellites into space as part of a quantum internet? Do we need to run experiments e.g. in the BNL NASA Space Radiation Facility to study the short and long term effects of radiation on quantum networking equipment?

- As we are thinking of science applications such as networked quantum enabled telescopes, what additional harsh environmental conditions would the quantum networking technology have to withstand?

- Detector Development – room temperature level
- High rate quantum entanglement sources (type I and Type II)
- Transduction –
- Low loss high-speed photonic switches
- Cryongenics?
  - Deployability
  - Is it needed – discussion?