Building a Quantum Internet

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- Introductory 20 year vision: “Imagine a world…”
- Phasing Strategy: What can a DOE project deliver in 10 years, 5 years, …
- Key experiments, milestones, decision points, timeline, requirements
- Impact on classical networking

From the draft report

- The process of building a Quantum Internet will follow DOE construction program guidelines. In accordance with those, a detailed set of procedures will be established and implemented.
- Although significant steps towards the development of critical components for the Quantum Internet have been made, the technology readiness still needs development.
- Several experiments are planned to answer key feasibility and scalability questions in the short term.
- To proceed with this time-sensitive and strategically competitive endeavor, we should use available infrastructures and plan a phased approach with each phase retiring risks and increasing technology readiness.

From the draft report

- Many activities in quantum network and communication, sensing and computing are rapidly advancing the level of quantum technology in the country with several teams [reff] producing very promising results.
- Coordinating the effort to further mature the technology with a focus on scalability and reliability and building the first Quantum Internet is the natural role of the DOE national laboratories.

From the draft report

- Established within this framework, the Quantum Internet will be built starting with the development of a small set of large nodes in key locations in the United States.
- Developing these nodes will allow to test different aspects in parallel, as well as potentially execute large-scale evaluations of various approaches in terms of their performance, reliability, and longevity.

From the draft report

- The outcome of this preliminary work will constitute the basis for the outline of the construction project.
- Typical construction projects follow the standard CD process, with baselined design, cost, and schedule refined throughout the life of the project.
- This model doesn’t meet the requirements of this developing field.
- A more suitable model is a staged approach unrolling the construction, starting with the creation of regional quantum networks that will be connected over time through an increasing number of pathways.

Moon shot goal(s)

“On demand teleportation of quantum states between any two nodes in a quantum network with at least ten nodes with high fidelity (95%, 99.9%, …)”

- Complex network topology, multi-path
- Data rate: >10 Hz, scale to kHz, …
- Without repeaters, 20 km, 5 y goal
  - With any technology, scalable or not
    - Dil fridge networks, rack mounted, not out of the question, ?
- With repeaters, 100+ km, 10 y goal
  - Hetero-qubit (e. g. SC-RF to ion traps to color enters to atomic)

What applications will be enabled by a network with these capabilities?

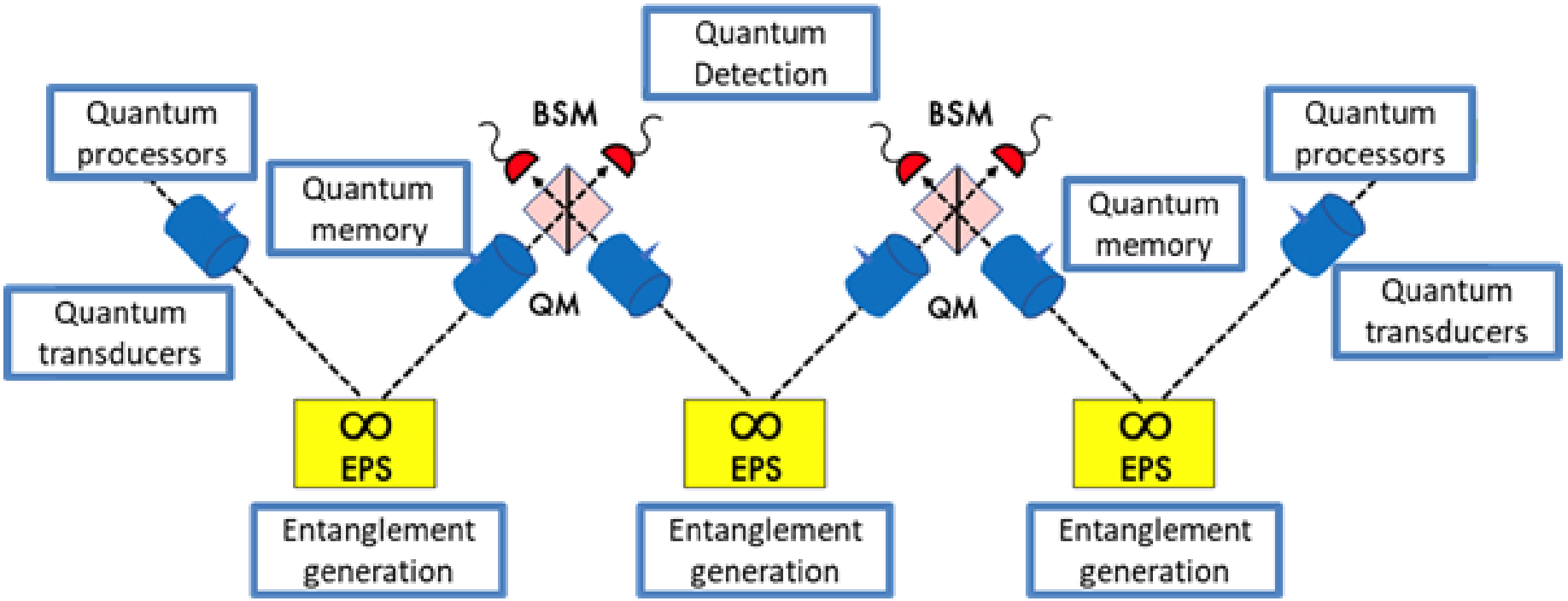
To reach this we need (probably)

- Quantum memory
  - Coherence time, fidelity requirements
- Quantum repeaters
  - Type 1 type, 2, …
- Synchronization
  - classical - quantum to tag and quantum – quantum to swap
- Network protocols for both
  - w/w-out q-repeater based
- **Network characterization**
  - classical – quantum, tracking and tomography, test, design, methods for benchmarking, figures of merit [analog to QC benchmarking, gate set tomography and result check], entanglement quantification, tracking/trouble shooting (noise sources, …)
    - Hard ware specific and higher level design rules
- Transduction
  - matter-photon, photon – photon
- Multiplexing optical channel
  - time – frequency
- Quantum – classical signal and control integration
- Control electronics and hardware, quantum switch, quantum router
  - Advanced material and device fabrication for non-linear optics, …

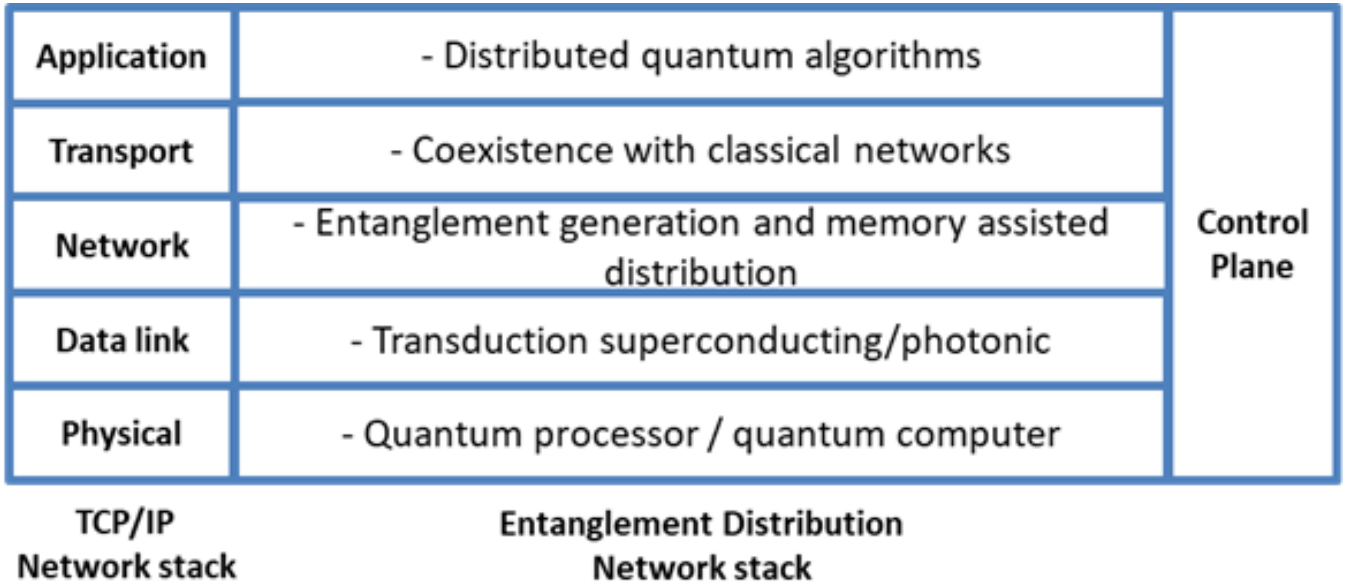
Let's establish **metrics** for scalable quantum networks

- Science vs. market metrics (vs. timeline, roadmap, TRL, …)
- End to end, node characterization, link by link
- Quantum network volume
  - Number of gates before error, number of teleportation events before error, …
- Fidelity
  - 95% → 99.95
  - Threshold for error correction
- Connectivity
- Complexity
- Success rate, efficiency
- Authentication (hardware/software, timing, security characterization, track performance, …)
- SWAPs, CSWA
  - Challenge driven, efficiency, market value, quantum state transfer/$; science applications vs. early market adapters, …
- For early high impact use cases, e. g. sensor network, …
- Quantum supremacy metrics for a "useful application"
  - Sensing: rate vs. precision, sensitivity

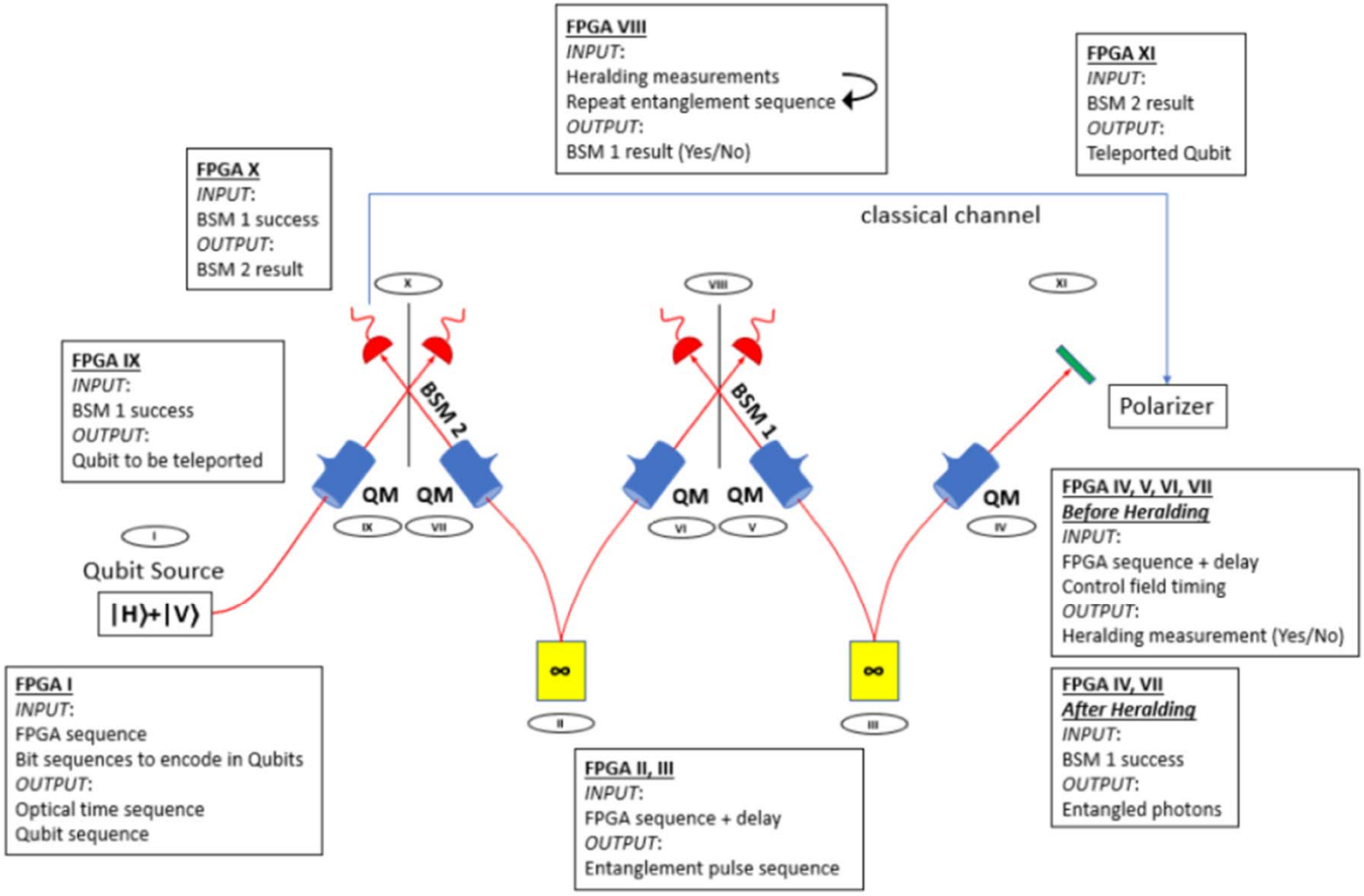
Entanglement Distribution Quantum Repeater Networks



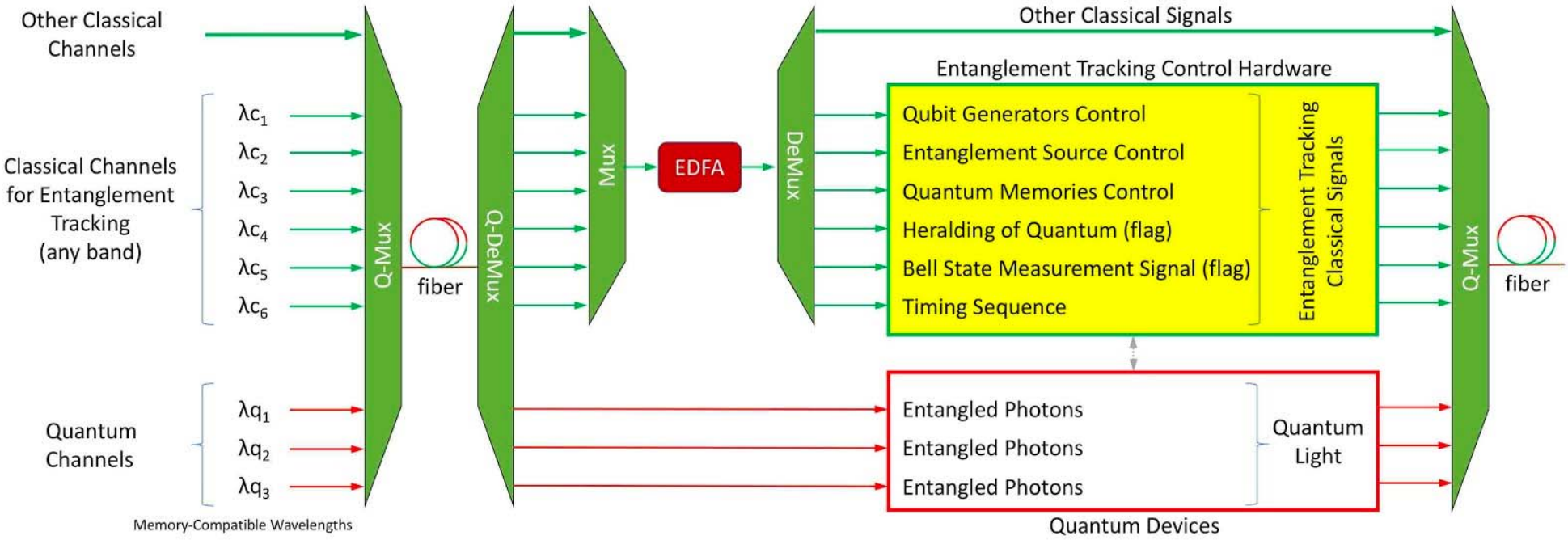
Quantum Internet Stack



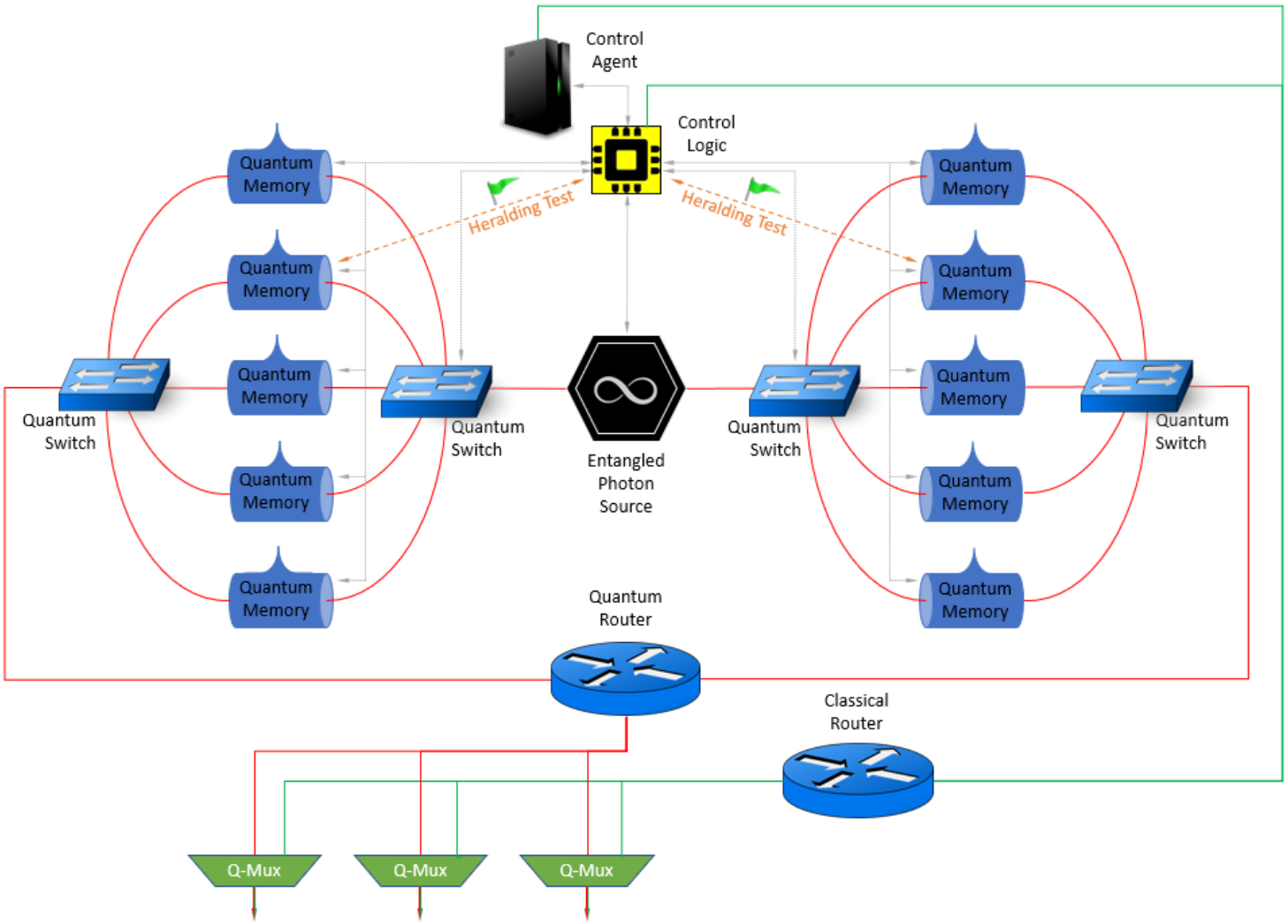
Quantum Hardware Layer



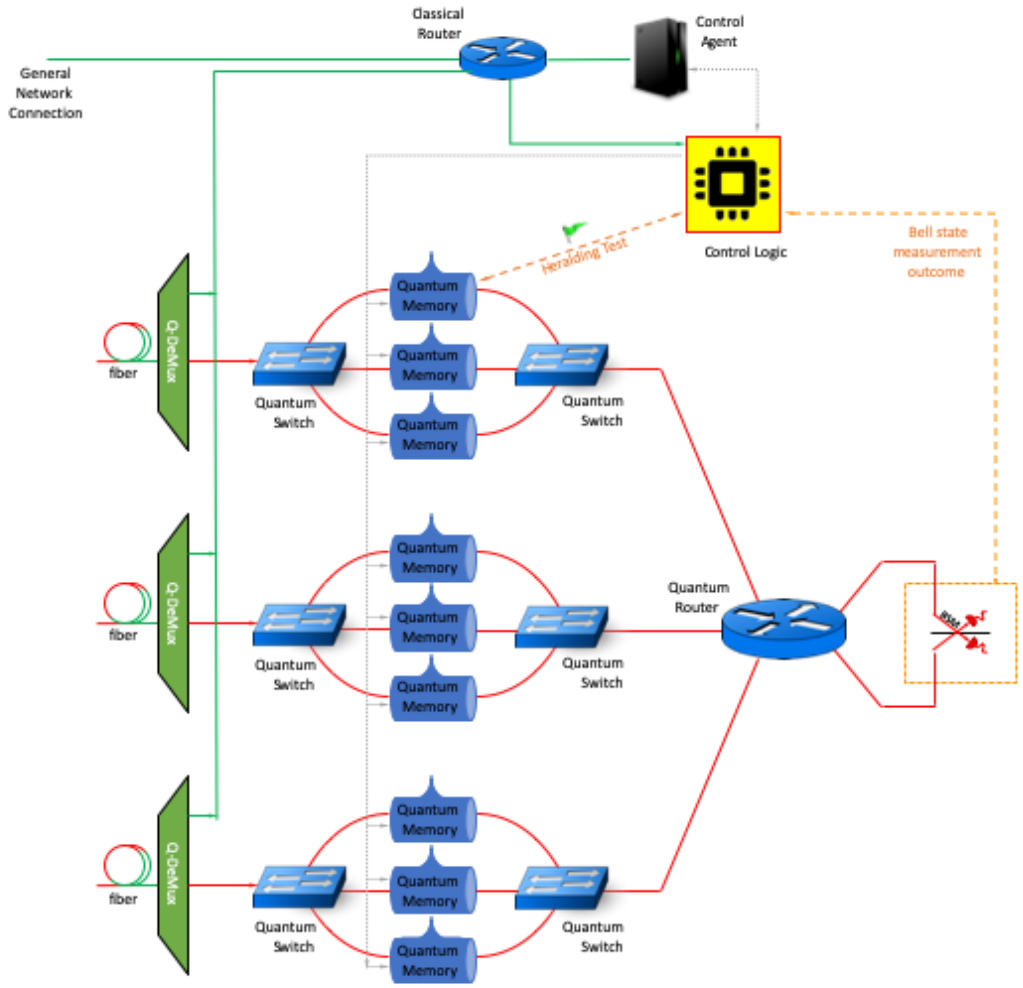
Quantum Link Layer



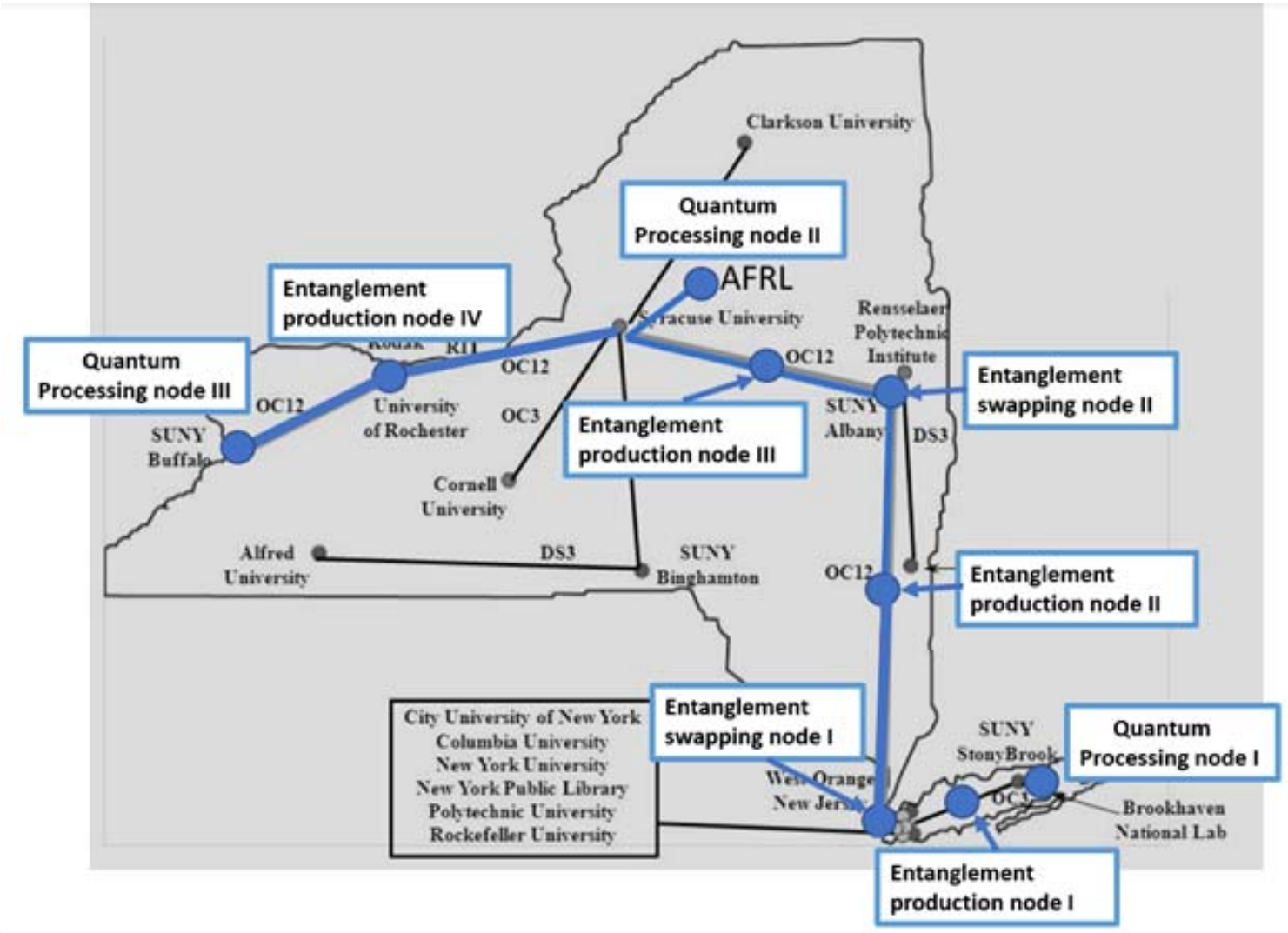
Node Type I: Quantum Entanglement Banks



Node Type II: Entanglement Swapping Nodes



Inter-city Quantum Networks: Quantum Repeater Links



Quantum switches and routing for more complex topologies