Quantum Internet Blueprint Workshop: Update

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BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

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Logistics

- **Goal**: Define a road map, how the community can move from individual quantum entanglement experiments today to building a first nationwide quantum Internet.
- **Organizing Committee**: Kerstin Kleese van Dam (Brookhaven), Inder Monga (ESnet), Nicholas Peters (ORNL), Thomas Schenkel (LBNL), Supratik Guha (ANL), Gabriella Carini (Brookhaven), Joseph Lykken (Fermilab), Panagiotis Spentzouris (FermiLab)
- **Workshop Dates**: February 05-06, 2020, SUNY Global Center, New York City
- **Attendees**: ~80 attendees, from DOE labs; universities
  - **Other Agencies**: AFRL, NRL, NASA, NIST, DoD, DARPA, NSF, OSTP
  - **Industry**: IBM, Google X, BBN, GE, Perspecta Labs, Xanadu, Battelle, Internet2, NYSERNET

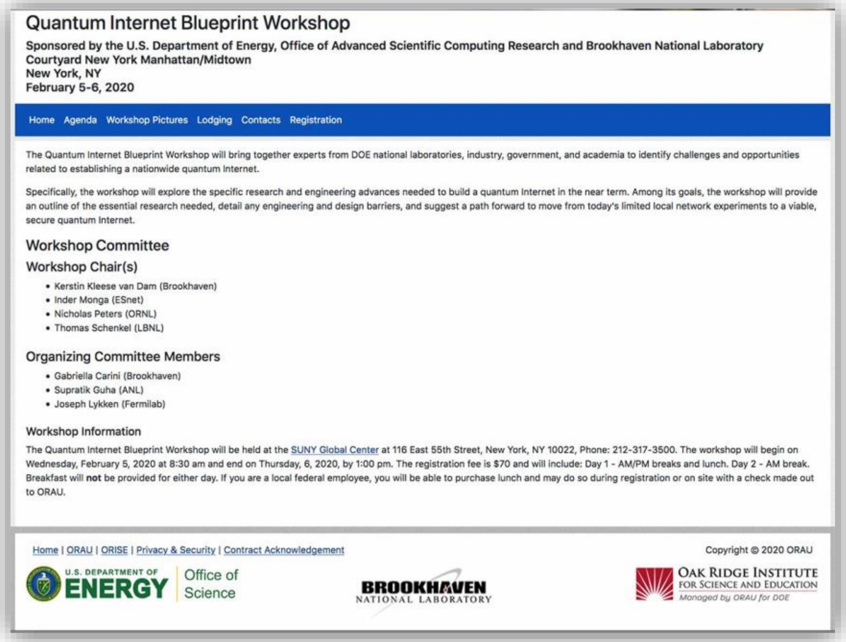
Agenda

Day 1

- **Motivational Talks**: Big Vision, International Status, U.S. Progress, Potential Early Adopters
- **Breakouts**: Quantum Hardware (two groups), Quantum Protocols
- **Plenary**: Quantum Internet Architecture Discussions

Day 2

- **Plenary**: Building a Quantum Internet



Quantum Internet Blueprint Workshop

Sponsored by the U.S. Department of Energy, Office of Advanced Scientific Computing Research and Brookhaven National Laboratory
Courtyard New York Manhattan/Midtown
New York, NY
February 5-6, 2020

Home Agenda Workshop Pictures Lodging Contacts Registration

The Quantum Internet Blueprint Workshop will bring together experts from DOE national laboratories, industry, government, and academia to identify challenges and opportunities related to establishing a nationwide quantum Internet.

Specifically, the workshop will explore the specific research and engineering advances needed to build a quantum Internet in the near term. Among its goals, the workshop will provide an outline of the essential research needed, detail any engineering and design barriers, and suggest a path forward to move from today's limited local network experiments to a viable, secure quantum Internet.

Workshop Committee

Workshop Chair(s)

- Kerstin Kleese van Dam (Brookhaven)
- Inder Monga (ESnet)
- Nicholas Peters (ORNL)
- Thomas Schenkel (LBNL)

Organizing Committee Members

- Gabriella Carini (Brookhaven)
- Supratik Guha (ANL)
- Joseph Lykken (Fermilab)

Workshop Information

The Quantum Internet Blueprint Workshop will be held at the SUNY Global Center at 116 East 55th Street, New York, NY 10022, Phone: 212-317-3500. The workshop will begin on Wednesday, February 5, 2020 at 8:30 am and end on Thursday, 6, 2020, by 1:00 pm. The registration fee is $70 and will include: Day 1 - AM/PM breaks and lunch. Day 2 - AM break. Breakfast will **not** be provided for either day. If you are a local federal employee, you will be able to purchase lunch and may do so during registration or on site with a check made out to ORAU.

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Workshop Outcomes

- A thorough assessment of state of the art in quantum networking
- Start toward building a multi-organizational community
- Four Priority Research Opportunities (PROs) identified
- Five Key Roadmap Milestones identified
- Workshop Brochure in Draft
  - Expected end of April/early May 2020
- Workshop Report in Draft
  - Expected end of May 2020

Priority Research Opportunities

PRO1: Provide the Foundational Building Blocks for a Quantum Internet

Key Question: What are the key building blocks of a quantum Internet, and what performance parameters do they need to satisfy?

- Today's quantum networking experiments rely on a set of devices with limited functionality and performance. However, it can be inferred from classical networks that in order to create wide-area, operational quantum networks, we need more capable devices with additional functionality. These new devices will need to satisfy suitable requirements for reliability, scalability, and maintenance. Potential network devices may include space-to-ground connections; high-speed, low-loss quantum switches; multiplexing technologies and transducers for quantum sources; as well as transduction from optical and telecommunications regimes to quantum computer-relevant domains, including microwaves.

PRO2: Integrate Multiple Quantum Networking Devices

Key Question: How will physical barriers to integrating multiple quantum network devices into high-performance quantum Internet components be overcome?

- Generally, all key quantum network components remain at laboratory-level readiness to date and have yet to be run operationally in a full network configuration. Moving forward will require overcoming critical challenges toward achieving cascaded operation and connectivity, among them unifying operational properties, achieving high-repetition rates (GHz), and devising quantum memory buffers and detectors to compensate for cascading operation losses.

PRO3: Create Repeating, Switching, and Routing for Quantum Entanglement

Key Question: How can fundamental network functions for a nationwide quantum Internet be created?

- Multi-hop networks require a means of strengthening and repeating signals along with selecting paths through the network. While physical and software solutions are used in classical networks, an equivalent has not been found for quantum networks. Challenges include different forms of quantum entanglement swapping, and quantum teleportation protocols over multiple users, as well as coordination and integration of traditional networks with quantum networks technologies for optimal control and operations.

PRO4: Enable Error Correction of Quantum Networking Functions

Key Question: How can fault tolerant network functions be achieved?

- A fundamental difference for quantum networks arises from the fact that entanglement, whose long-distance generation is an essential network function, is inherently present at the network's physical layer. This differs from classical networking, where shared states typically are established only at higher layers. In this context, solutions must be found to guarantee network device fidelity levels capable of supporting entanglement distribution and deterministic teleportation, as well as quantum repeater schemes that can compensate for loss and allow for operation error correction.

Quantum Internet Blueprint Roadmap

Cross-cutting Milestone: Build a Multi-institutional Ecosystem

- To implement this quantum communication infrastructure and actualize it into a full-fledged prototype of a Quantum Internet, **coordination and cooperation with other federal agencies are paramount**.
- Interactions between agencies with substantial quantum networking portfolios and those with key mission needs in this space, including DOE, NSF, NIST, DoD, NSA, and NASA, are particularly relevant.
- While pursuing these alliances, critical opportunities for new directions and spin-off applications should be encouraged by robust cooperation with quantum communication startups and large optical communications companies. **Early adopters can deliver valuable design metrics.**

Milestone 1: Verification of Secure Quantum Protocols over Fiber Networks

Prepare and Measure Quantum Networks

- In this quantum network prototype, **end users receive and measure quantum states, but entanglement is not necessarily involved**. Users can have their password verified without revealing it, and two end users can share a private key known only to them. Applications to be achieved in this kind of network include quantum key distribution (QKD) between non-trusted nodes with (comparatively) higher tolerance on timing fluctuations, qubit loss, and errors.

Milestone 2: Inter-campus and Intra-city Entanglement Distribution

Entanglement Distribution Networks

- In this type of quantum network, **any two end users can obtain entangled states**, requiring end-to-end creation of quantum entanglement in a deterministic or heralded fashion, as well as local measurements. These networks provide the most robust quantum encryption possible by enabling implementation of device-independent protocols, such as measurement device-independent QKD and two-party cryptography. The tolerance for fluctuations, loss, and errors is lower than the previous class (Milestone 1). Initial integrations of classic and quantum networks exists.

Milestone 3: Intercity Quantum Communication using Entanglement Swapping

Quantum Memory Networks

- In this type of quantum network, **any two end users (nodes) can obtain and store entangled qubits and teleport quantum information to each other.** End nodes can perform measurements and operations on the qubits they receive. The minimum memory storage requirements are determined by the time for round trip classical communications. This quantum network stage enables limited cloud quantum computing in the sense that it allows a node with the ability to prepare and measure single qubits to connect to a remote quantum computing server.

Milestone 4: Interstate Quantum Entanglement Distribution using Cascaded Quantum Repeaters

Network Connectivity

- **Classic and quantum networking technologies have been integrated**. Successful concatenation of quantum repeaters and **quantum error corrected communication** with respect to loss and operational errors over continental-scale distances, will pave the way for operational entanglement distribution networks covering longer distances, **enabling a first-ever quantum Internet to be created.**