Center for Quantum Networks (CQN)

University of Arizona (lead institution)

Developing the Quantum Internet

Center for Quantum Networks

A National Science Foundation Engineering Research Center since 2020

Partner Institutions:

- ***University of Arizona (lead institution)***
- ***Harvard University***
- ***Yale University***
- ***Massachusetts Institute of Technology***

Vision: CQN will lay the foundations for a socially responsible quantum Internet that will spur new technology industries and a competitive marketplace of quantum service providers and application developers.

The Center for Quantum Networks (CQN) is taking on one of the great engineering challenges of the 21st century: to lay the technical and social foundations of the quantum Internet. The quantum Internet will surpass the capabilities of today's Internet because of the unique advantages of entanglement—a coordination of the quantum states of particles serving as computational bits in a way that is not possible in the realms of classical physics.

CQN brings together experts with diverse backgrounds to develop the entire stack of device technology and theoretical research to realize the vision of a scalable quantum Internet. The quantum Internet will provide the new service of *quantum communication* that is not possible today: The act of transmitting quantum bits (qubits) reliably at high rates among multiple users simultaneously, supporting a range of new applications that will have far-reaching impacts for technology and society. Being able to transport qubits will enable distributing quantum entanglement among far-flung locations.

At the heart of CQN's research is the development of a fault-tolerant quantum repeater along with the enabling quantum devices and the associated network protocol stack. Quantum repeaters will enable long-range quantum communication, which is not possible with classical photonic hardware such as fibers, lasers, switches, and amplifiers. CQN anticipates that in addition to fiber-optic repeaters, satellite-assisted transcontinental and intercontinental optical quantum links will also play an integral part in realizing the quantum Internet.

This new service of quantum communication will improve the Internet in at least two important ways. First, it will enable physics-based provable communication security that cannot be compromised by any amount of computational power. Second, the quantum Internet will create a global network of quantum computers and processors, as well as ground- and space-based sensors, that are fundamentally more powerful than today's technology. This will bring unprecedented advances in distributed computing and the Internet of Things, and it will enable secure access to cloud-based quantum computation for the public.

CQN aspires to become an idea-generation hub and epicenter driving the maturation of the new discipline of Quantum Information Science and Engineering (QISE). CQN's closely intertwined research and educational missions will prepare the quantum-trained engineering workforce of the 21st century.

RESEARCH

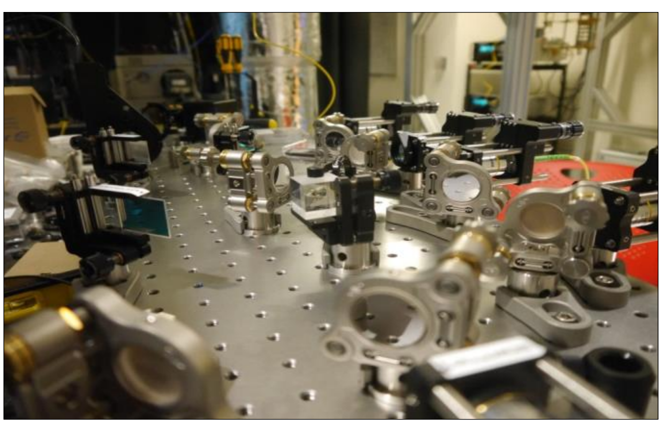
The technical goal of CQN is to develop an error-corrected quantum network serving multiple user pairs, supported on a network backbone made of optical fibers, switches, and quantum repeaters built using fault-tolerant quantum memories and qubit-photon transduction devices. The technical goal can be broken into three thrusts, operating at different layers and scales. CQN research also includes a fourth thrust: a focused study of the social, economic, and political context so that the quantum Internet is designed and built to function well in a practical, and not purely technical, sense.

CQN's four thrusts are:

Thrust 1: Quantum network architecture CQN's computer scientists and network engineers are working with optical physicists and material scientists to design architectures and a network protocol stack for a quantum Internet that seamlessly interoperates with the classical (conventional) Internet. These protocols are being tested at two CQN testbeds, being built in Tucson and Boston, respectively.

Thrust 2: Quantum sub-system technologies The only way to achieve long-distance terrestrial quantum communications networks will be by using fault-tolerant quantum repeaters. These quantum repeaters are special-purpose quantum processors that enable high-speed communication of the quantum states of entangled qubits over long distances. The quantum repeater is the key subsystem being developed by this thrust. The quantum repeater is being built by assembling its key subcomponents—quantum memories, sources of entangled photons, quantum frequency-conversion, photon-qubit transduction, superconducting nanowire detectors, and error correction codes—and is being tested, validated, and improved in both of the CQN testbeds.

Thrust 3: Quantum materials, devices, and fundamentals The repeaters, as well as other special-purpose quantum computing devices like networking gateways, will require quantum memories, with specialized interfaces to the modern telecommunications infrastructure. Each of these subcomponents presents its own engineering challenges and requires collaboration across multiple disciplines such as materials science and photonic engineering.



Confocal optical apparatus to be used in quantum networking experiments in Marko Loncar's laboratory at Harvard University (Credit: Harvard University)

Thrust 4: Societal impact of the Quantum Internet In addition to the technical innovations, CQN is working to ensure that society is well prepared for broad, affordable, and equitable access to the quantum Internet and its ensuing economy. CQN is proactively studying the social and policy implications of this budding technology. To do this, CQN supports social science research into the legal, economic, and social implications of quantum communications, and will leverage the insights from this research to inform and give guidance to industry, policymakers, and the public at large.

EDUCATION

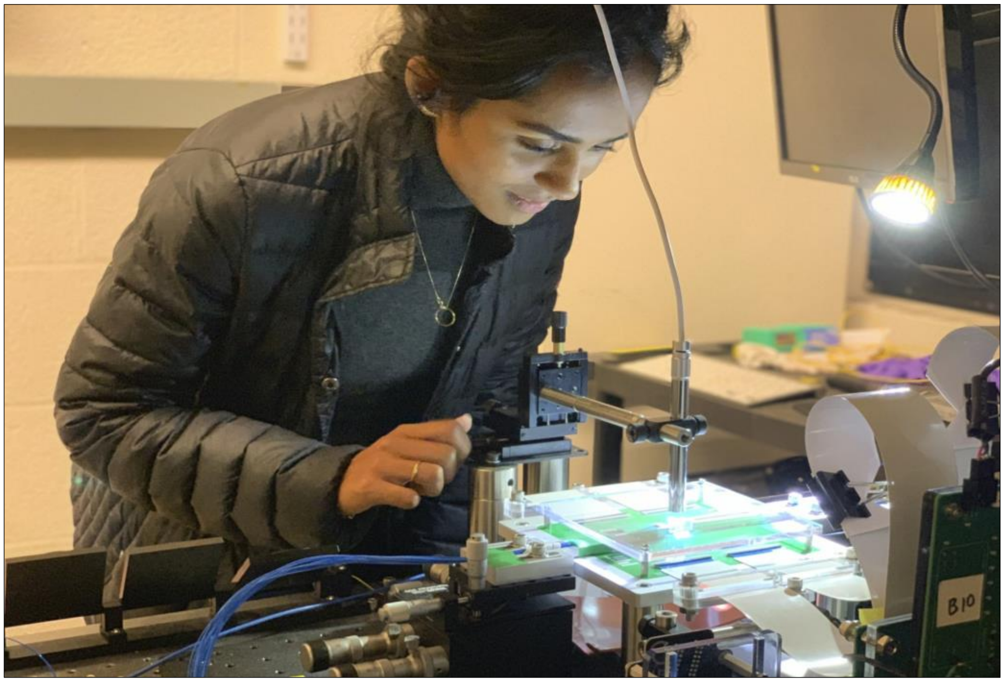
CQN fosters an understanding of, and curiosity about, quantum communications within a diverse range of communities and students. At the university level, CQN is developing curriculum and teaching materials for a new discipline: Quantum Information Science and Engineering (QISE), starting with a new Master's degree. CQN is also developing post-graduate and mid-career training programs for industry partners. To address the issue of ensuring that enough students enter the QISE pipeline, CQN is developing multiple outreach programs to middle-school and high-school students, designed to spark awareness of careers in quantum information science and engineering.

The core values of CQN's Engineering Workforce Development (EWD) efforts are:

- To go beyond just educating students and employees in new skills
- To use talent development as a major component of the Center
- To be inclusive across all CQN thrusts and pillars
- To develop teaching materials and the ability to teach others
- To ensure diversity and facilitate a culture of inclusion

DIVERSITY AND CULTURE OF INCLUSION

Research and training in Quantum Information Science & Engineering must be available to everyone. This is imperative for fairness reasons as well as for pragmatic reasons—U.S. industry and universities will have a great demand for professional, conscientious colleagues who are both capable of and comfortable with working in the field of quantum engineering. CQN will help broaden the base of expertise. CQN is creating a nurturing and respectful environment in all CQN labs, classrooms, and cross-campus collaborations for the



Mihika Prabhu of MIT aligns optical components to couple light into a photonic integrated circuit. (Credit: Massachusetts Institute of Technology)

Center using practices, trainings, and interventions that have been proven to foster engagement and mutual respect. All research labs will participate in intercampus rotation programs and community outreach activities as well.

Moreover, CQN will also ensure that the quantum networking technology itself is developed and rolled out in a manner that is equitable. Transformational technologies are not always accessible to everybody, and they can inadvertently exacerbate disparities that already exist between more-privileged and less-privileged communities. To ensure that CQN is aware of the distributional effects of new quantum communications technologies, CQN inclusion leadership will participate in the selection of Quantum Society projects supported through the Center's social science research thrust.

INNOVATION ECOSYSTEM

CQN is designed to act as an innovation hub, connecting NSF-funded research to multiple external partners, including startup companies, established industrial enterprises, Federal laboratories, and more. Many of these connections are made through the CQN Industrial Partnership Program (IPP), which is open to companies of all sizes, including faculty spinouts. The objective of the IPP is to establish an innovation ecosystem (IE) that will continue to thrive beyond the lifetime of the ERC.

Industry partners are invited to help shape the direction of CQN's research efforts through semi-annual meetings with research staff as well as other interactions throughout the year. Partners are also encouraged to sponsor associated research programs with PIs and other university researchers affiliated with CQN. The Center has an active technology-transfer program granting generous non-exclusive research rights to IPP partners and leverages multiple campus entrepreneurship programs to support the establishment of startups and spinouts.

Industrial partners play an important role in developing and maintaining the curriculum for the Center's QISE education programs at all levels. The IPP facilitates industry internships for CQN graduate students, as well as opportunities for industry experts to spend time in university labs and testbeds. Finally, the IPP develops and maintains the CQN Application Roadmap, helping the Center remain focused on commercial uses of quantum networking that will strengthen American economic competitiveness.

FACILITIES

CQN leverages existing laboratory infrastructure at the University of Arizona, Harvard, Yale, and MIT. The Center is building two quantum networking testbeds: one in Tucson, and one in Boston; these will establish cutting-edge infrastructure to enable multi-party quantum entangled communication as well as complex quantum networking capability, both over optical fiber and through free space. CQN will also occupy a 15,000 sq. ft. floor of custom-configured laboratory and office space in a new research building being built at the University of Arizona adjacent to the Wyant College of Optical Sciences.

CQN is headquartered at the Meinel building in the Wyant College of Optical Sciences at the University of Arizona (Credit: University of Arizona)

CENTER CONFIGURATION, LEADERSHIP, TEAM STRUCTURE

The Director of CQN chairs a Leadership Team (LT) comprising two co-Deputy Directors and an Administrative Director, who are responsible for visioning, creating an inclusive culture, decision-making, and budgeting. The LT leads strategic planning and assessment involving all thrusts and pillars. The LT consults monthly with the Executive Committee (EXCOM)—comprised of the LT, Thrust co-Leads, EWD and DCI co-Leads, and IE Lead—to review, develop, and approve all CQN roadmaps, milestones, and objectives on annual, five-year, and ten-year horizons. The EXCOM evaluates CQN's scientific and broader impacts progress and operations, as well as provides continual feedback and recommendations. In addition, the Director consults periodically with the NSF ERC Program team as well as an External Advisory Board to discuss progress, challenges, and planned changes.

CENTER HEADQUARTERS

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