The bridge to possible

Cisco Quantum Network Digital Twin

The Quantum Network Development Kit

Dr. Reza Nejabati
Head of Quantum Research

BRKETI-2445

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Quantum Research & Development

Explore the bizarre and mind-blowing world of quantum technologies and learn about the ground-breaking research & development advances Cisco is making to become the industry-leader in quantum networking

START

Tuesday June 4 | 10:30 am

BRKETI-1401

An Introduction to Quantum Mechanics, Computing, and Networking

Tuesday June 4 | 1:30 pm

PSOETI-1402

Cisco Quantum Network Vision & Strategy

FINISH

Wednesday June 5 | 10:30 am

BRKETI-2445

The Quantum Network Development Kit: Quantum Network Simulation Made Easy

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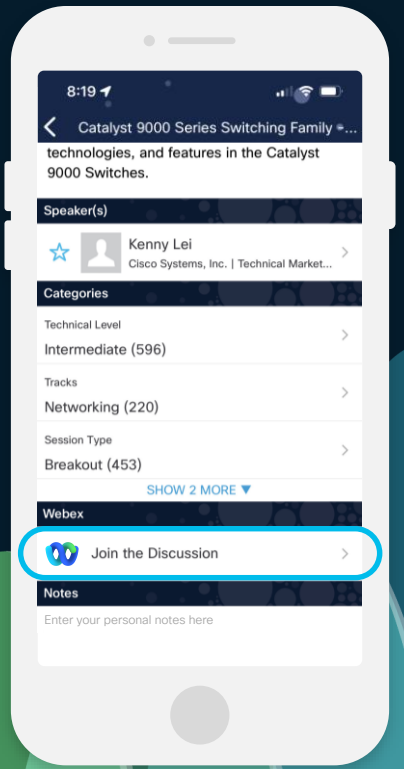
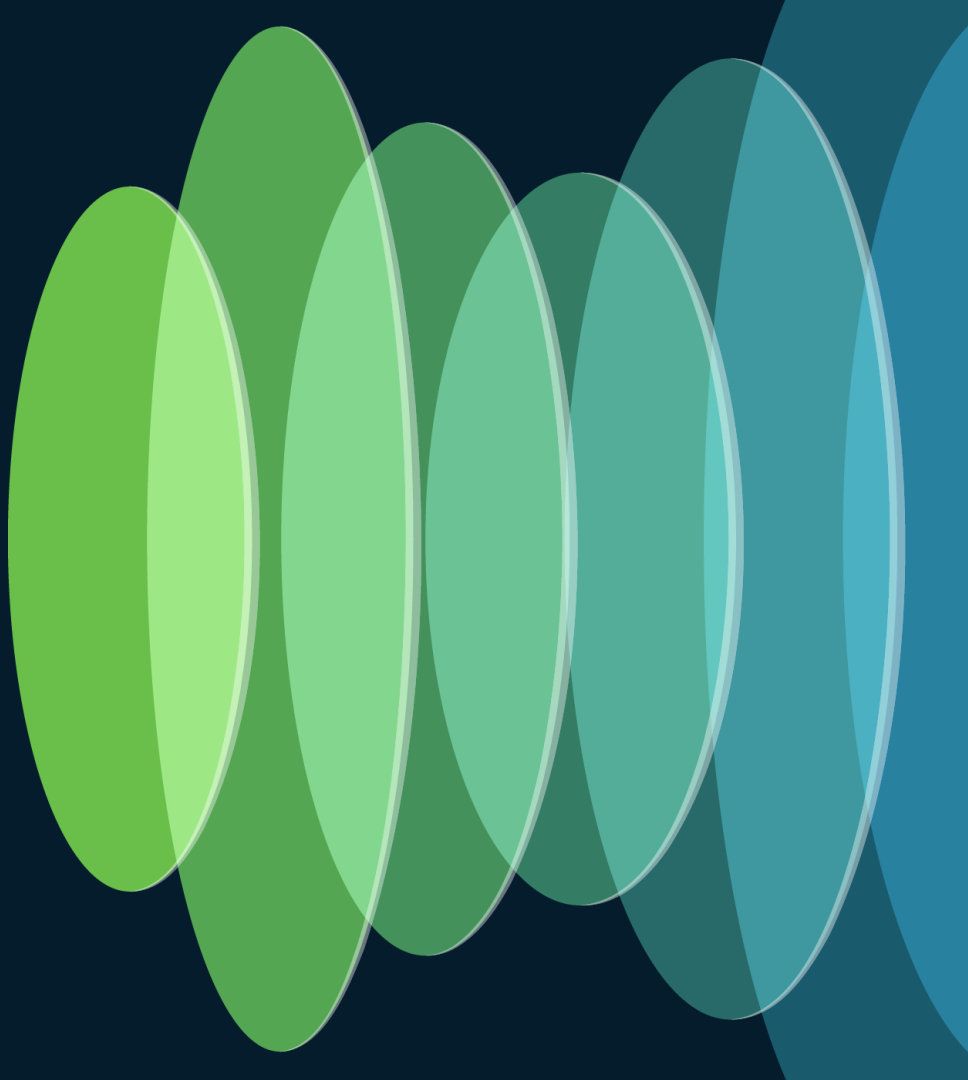


Agenda

- Power of Quantum Mechanics
- Building a Practical & Useful Quantum Network
- Scalable Quantum Computing
- Quantum Network Digital Twin
- Demos

Harnessing Power of Quantum Mechanics

A Cisco View



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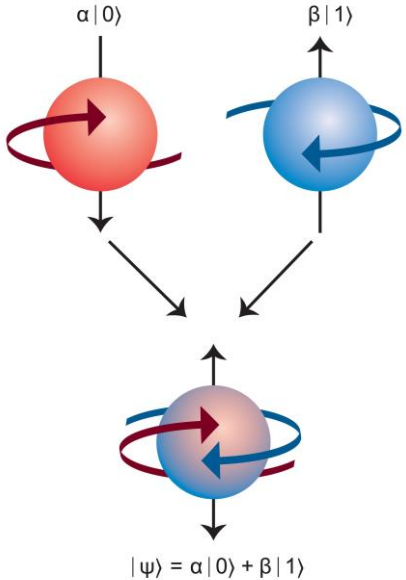
Harnessing Power of Quantum Mechanics

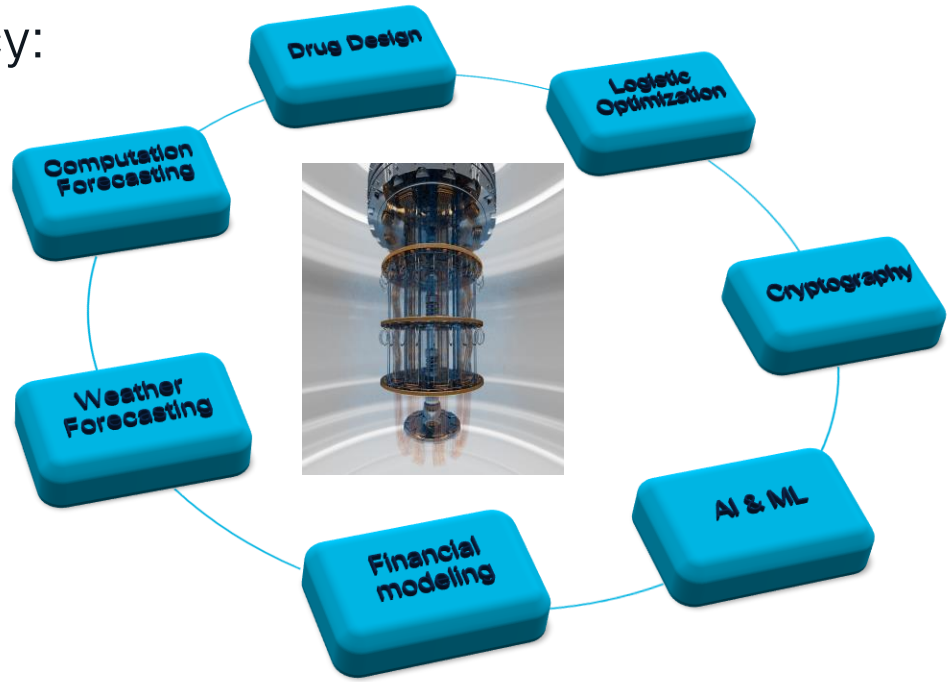
- Classical bit : 1 or 0
- Quantum bit (qubit): $\alpha\ |1\rangle + \beta\ |0\rangle$, $|\ \alpha\ |^2 + |\ \beta\ |^2 = 1$

- Generating qubit:
  - Nuclear Spin, Electron Estate , Photon Polarization



Harnessing Power of Quantum Mechanics Quantum Computers

- Quantum Computing Supremacy:
  - 2 qubits: superposition of 4 possible basis states
  - 3 qubits: superposition of 8 possible basis states
  - n qubits: superposition of 2^n possible basis states

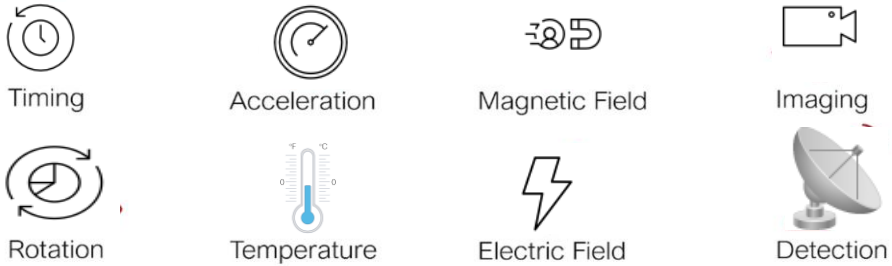


Quantum Sensing

- A quantum sensor utilizes properties of quantum mechanics and environmental effect
  - Quantum Sensor : Quantum sources + measurements
  - They exploit quantum states that are highly sensitive to disturbance

- They have optimized precision and beat current limits in sensor technology.

- Quantum technology has already impacted on existing sensing technology, with improvements by as much as 10,000 times

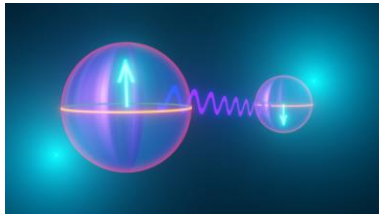


Harnessing Power of Quantum Mechanics Quantum Security

- No cloning theorem
  - It is impossible rot create an indexical copy of an arbitrary unknown quantum state
  - There is no operation that copy an arbitrary state of a qubit

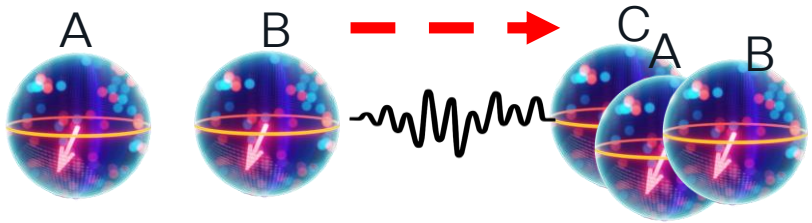
Harnessing Power of Quantum Mechanics Entanglement

- Two qubit can be entangled
  - An entangled pair is a single quantum system in a superposition of equally possible states.
  - A measurement of one qubit will affect the state of another qubit at distance
  - Even though classically there is no direct interaction



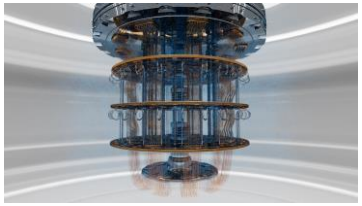
Harnessing Power of Quantum Mechanics Teleportation

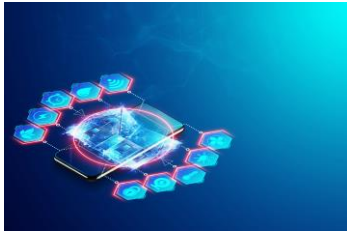
- **Quantum Teleportation** is the process by which quantum information (e.g. exact state of a photon) can be transmitted
  - Quantum Teleportation involves entangling two Photon
  - Qubit B & Qubit C are entangled and forming teleportation channel
  - Qubit A to be teleported is combined with Qubit B
  - This change instantly teleported to Qubit C
  - **However receiver can not reconstruct A without help of sender**

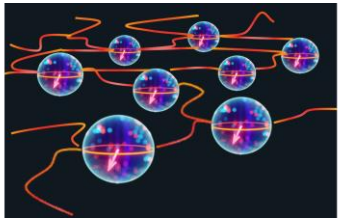


Quantum Supremacy

- Ultimate physical layer security
  - No Cloning property of quantum bits
    - Quantum Key Distribution (QKD)
- Computing supremacy
  - Superposition of states in quantum bits
    - Quantum Computing
- Highly accurate and high-resolution sensing
  - Superposition of quantum is sensitive environmental effect
  - Quantum Sensing
- New dimension in networking
  - Quantum entanglement for quantum computer and sensor interconnect
  - Quantum entanglement for information teleportation

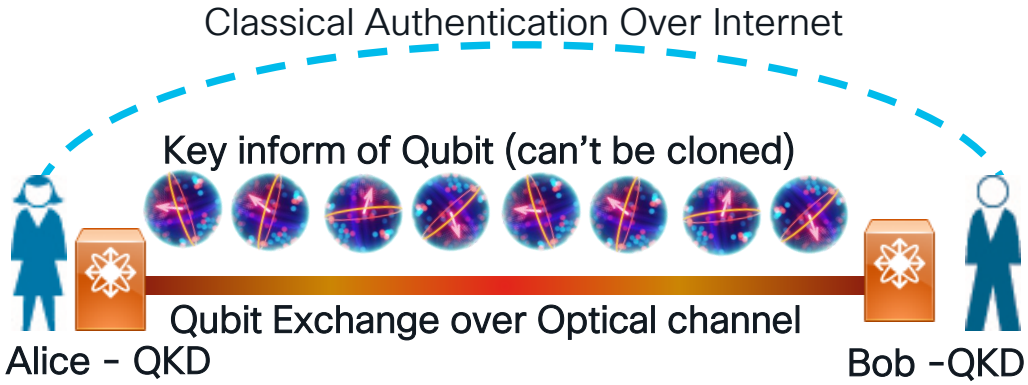






Today's Commercial Quantum Networks State-of the-Art

- Existing quantum networks
  - Point-to-Point
  - For security use-cases: quantum key distribution QKD
  - Dedicated fiber or frequency band (O-band)



- Major QKD Networks
  - China National Integrated QKD Network
    - Long distance Fiber + Satellite
    - Point to Point
  - London QKD Network by British Telecom (BT)
    - Fibre Ring in London City
    - Point to Point

Today's Commercial Quantum Networks The Problem

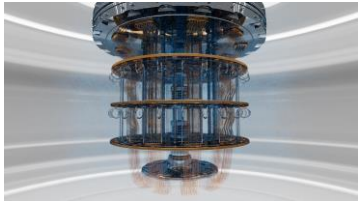
- Point-to-Point quantum connectivity
  - **Static, no dynamicity, no switching, no routing**
- Specific to security use cases
  - For quantum key distribution QKD
  - Not a full security solution : Securing only optical Link, not end nodes or wireless
- Needs dedicated HW, dictated fiber, dedicated frequency band or very large guard band
- **Costly and not scalable**
- **It is not efficient and robust enough to support applications beyond security**

Cisco Quantum Network Vision

Cisco Quantum Network

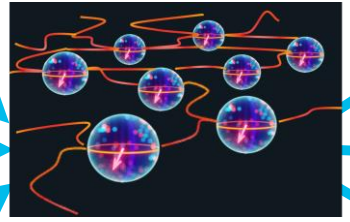
Quantum Security

Quantum Computing



Quantum Sensing

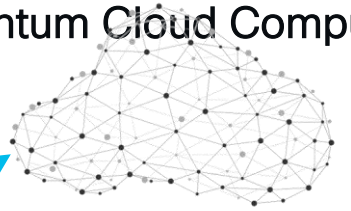
Multi-User & Multi-Tenant



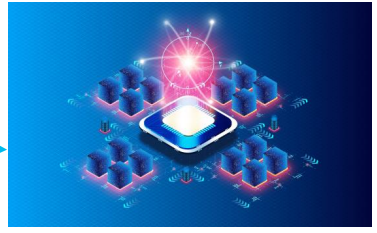
Quantum Network
Dynamic, Entanglement, Co-existence

Quantum Network
Control

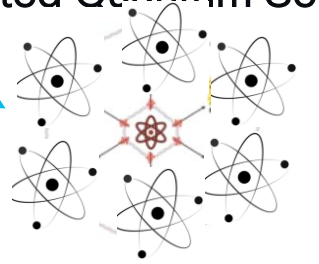
Quantum Cloud Computing



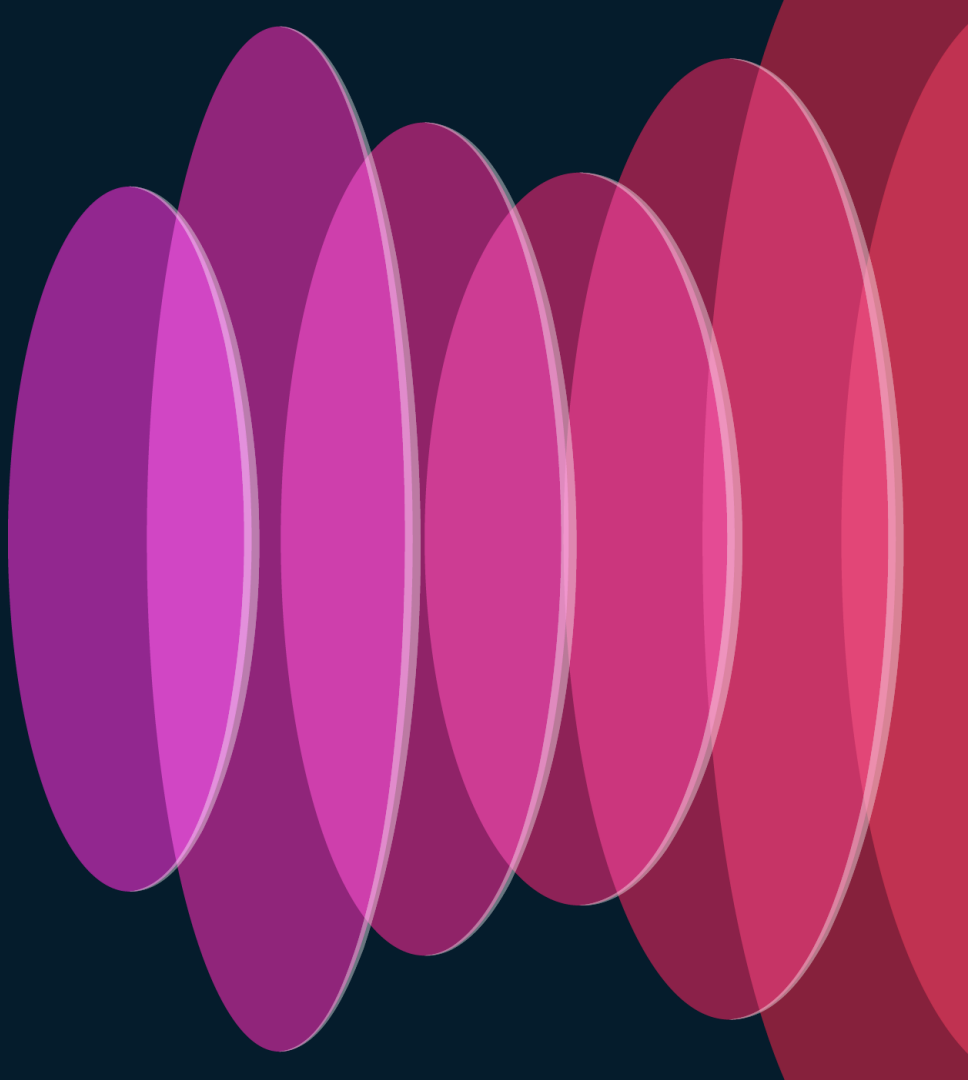
Quantum Data Center



Distributed Quantum Sensing



Building a Practical & Useful Quantum Network



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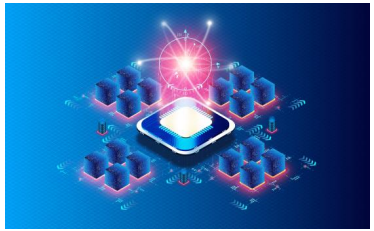
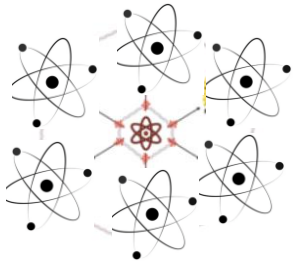
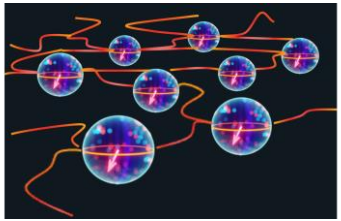
Cisco Quantum Network Vision

- Beyond security applications
  - Supports applications beyond QKD such as distributed quantum computing and sensing
- Support large number of users and end points
  - Scalable
  - Multi-tenant
  - Virtualizable
- A dynamically switched and routed network
  - Route and switch quantum channels on demand
- Doesn't need necessarily a dedicated fiber infrastructure

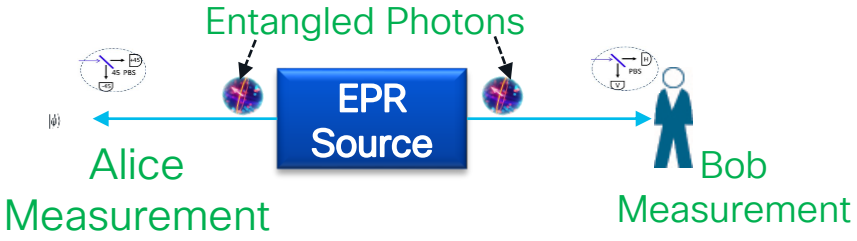


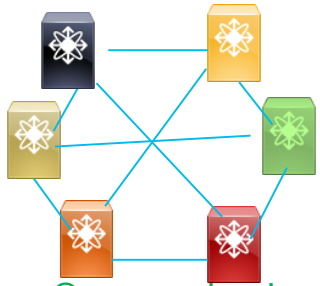




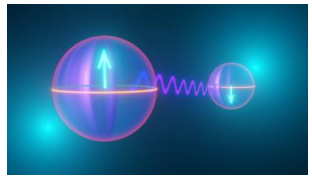
Harnessing Power of Quantum Entanglement

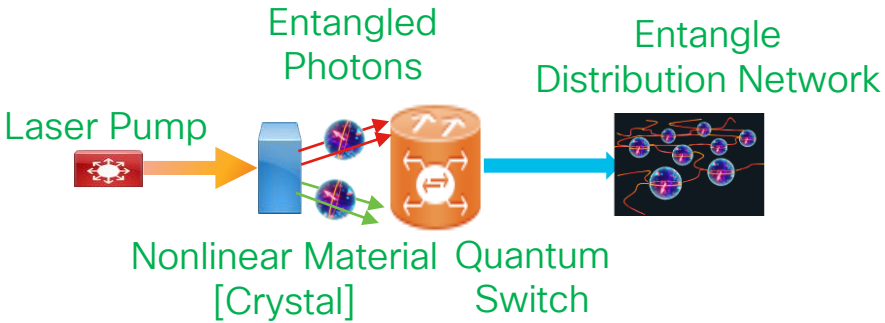
- Two qubits can be entangled
  - A measurement of one qubit will effect the state of another qubit at distance

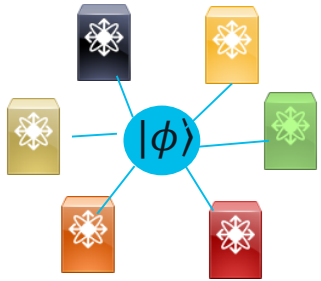




Entanglement Communication layer



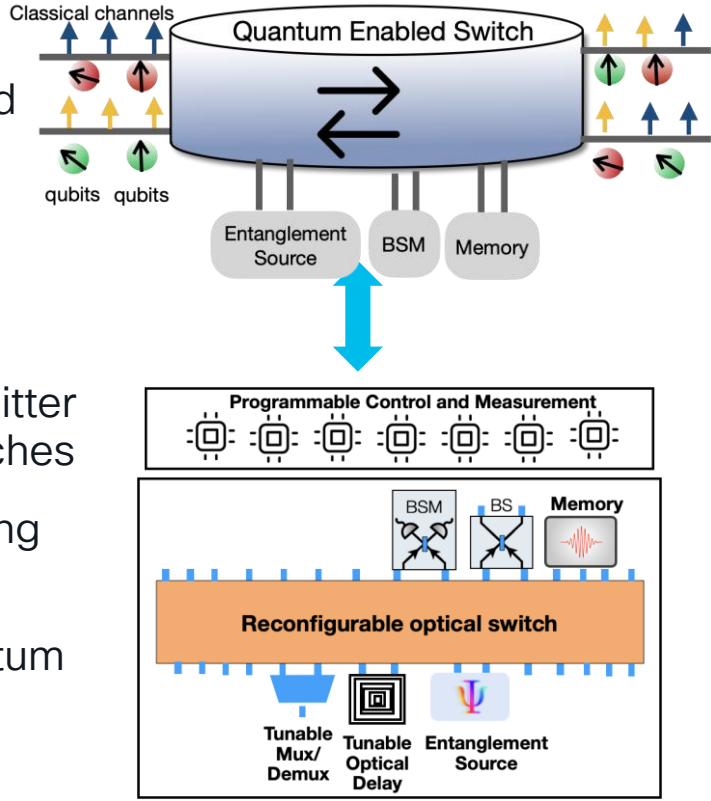




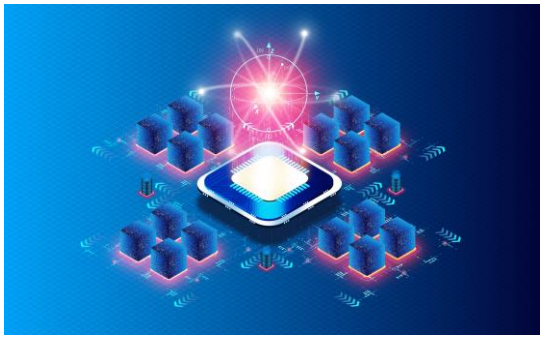
Entanglement Physical layer

Cisco's Quantum Enabled Switch

- High connectivity: Non-blocking switching of entangled photons from any input ports to any output ports
- High flexibility: Supporting multiple modes of entanglement including time bin, frequency bin, and polarization-based entanglement.
- High accuracy and efficiency: Ultra-low loss and time jitter port to port switching, allowing cascade ability of switches
- Scalability: Supporting pluggable for on-demand sharing across networks
- Hybrid switching: Support for both classical and quantum communication



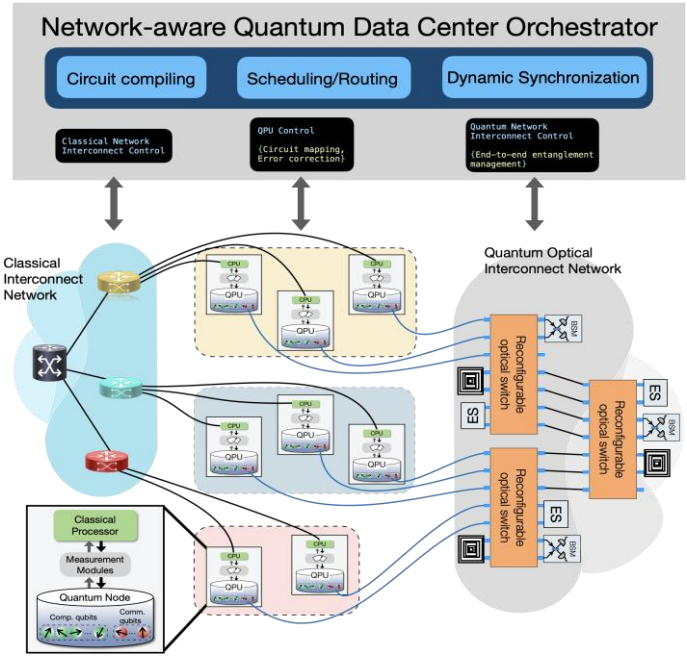
Quantum Data Centers



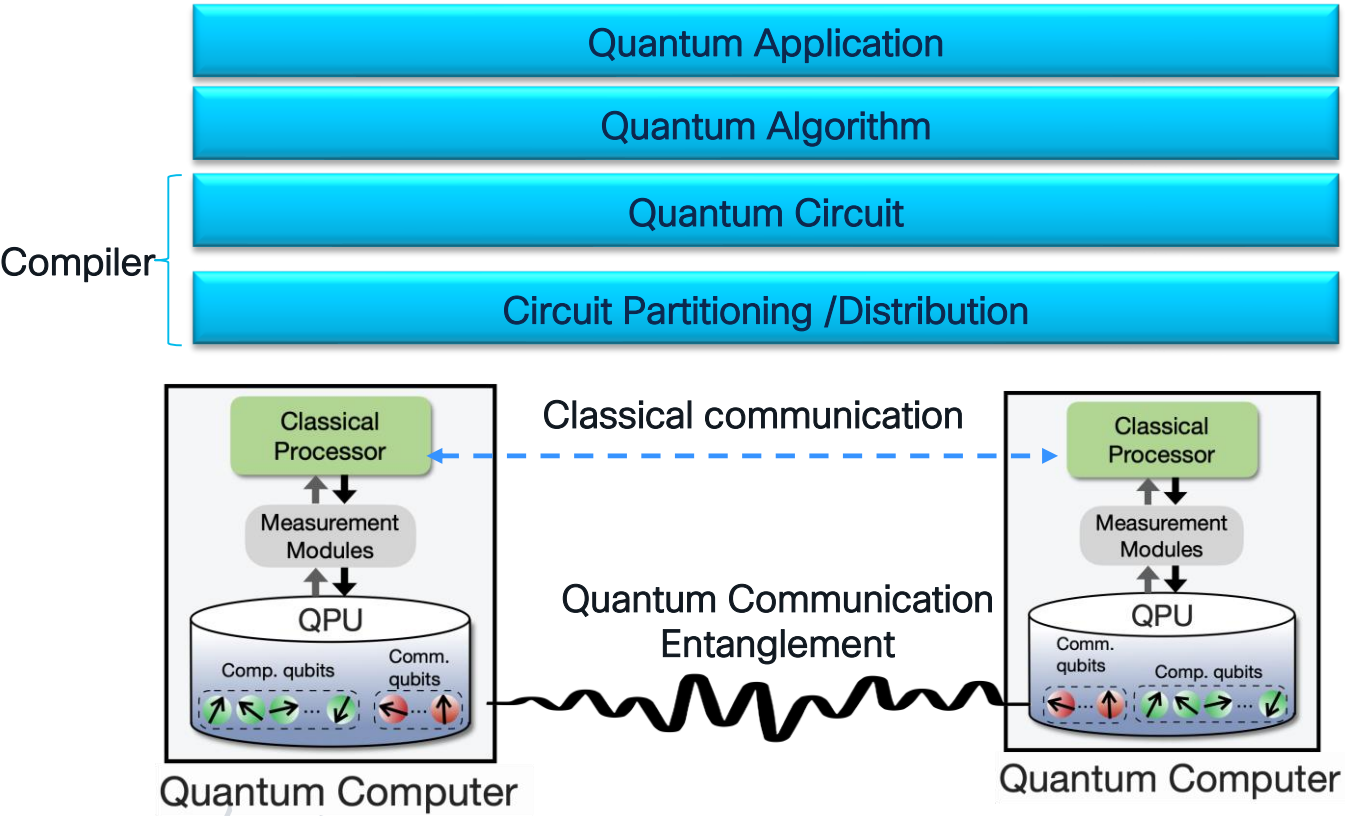
- What is a Quantum Data Center
  - Warehouse scale distributed quantum computing
- Why a quantum data center
  - A useful Quantum Computer should be large enough
    - More than 20 Million Qubit
  - Monolithically scaling a single quantum computer is not possible and economical
    - A 1 M qubits processor needs football pitch size cooling system
    - Control /measurements system become too complex
- Solution: Building a quantum datacenter
    - Hyper scalers' approach
    - Create a scalable quantum computing by networking large number of small processor

Cisco Vision for Quantum Data Center Architecture

- Modular and scalable
- Support multi-tenancy
  - Multiple, co-existing, and independent logical interconnect topologies.
  - Any-to-any connectivity between quantum processors.
- Support heterogeneous quantum computing platforms.
- Sharing critical resources, such as detectors and Bell State Measurement (BSM) devices,
- Utilize Quantum network-aware orchestrator

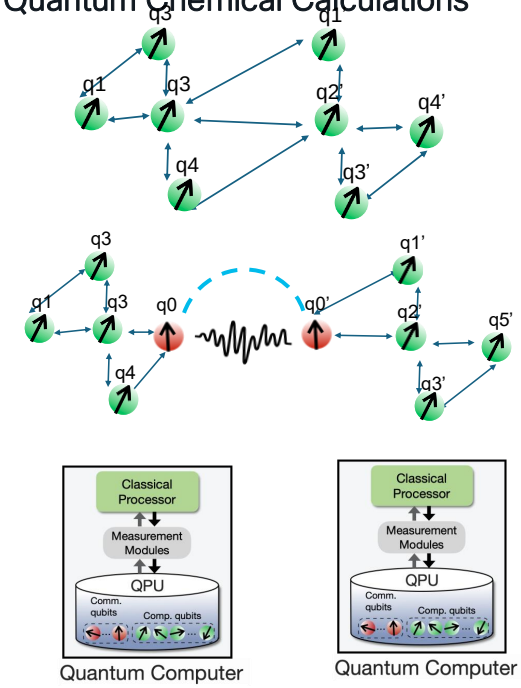


Distributed Quantum Computing

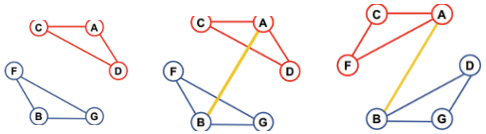


Drug Design

Quantum Chemical Calculations

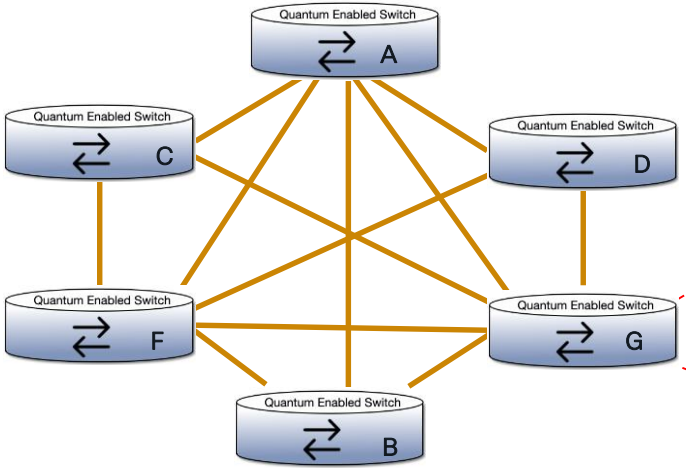


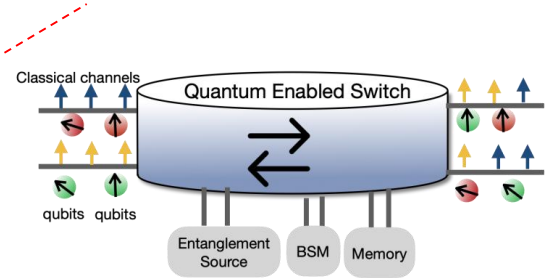
Building Logical Quantum Network : Towards Multi-Tenant and Scalable Quantum Networking



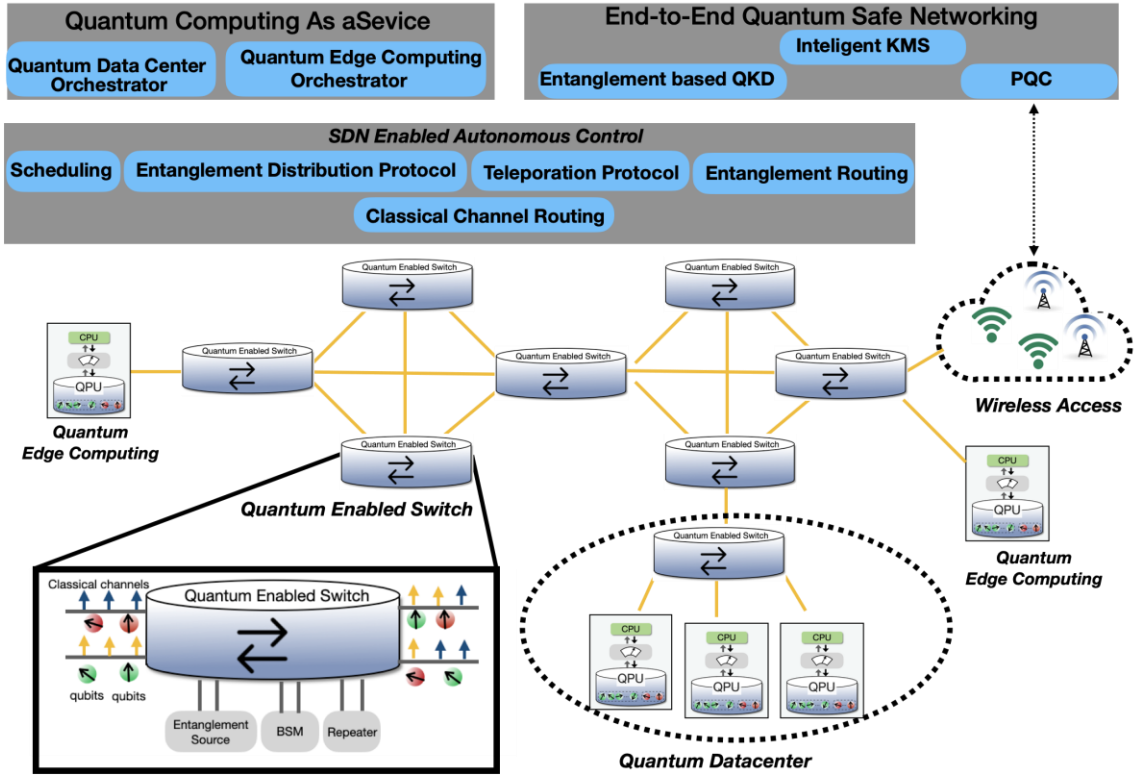
SDN Enabled Autonomous Control

- Entanglement Distribution Protocol
- Entanglement Routing
- Scheduling
- Classical Channel Routing

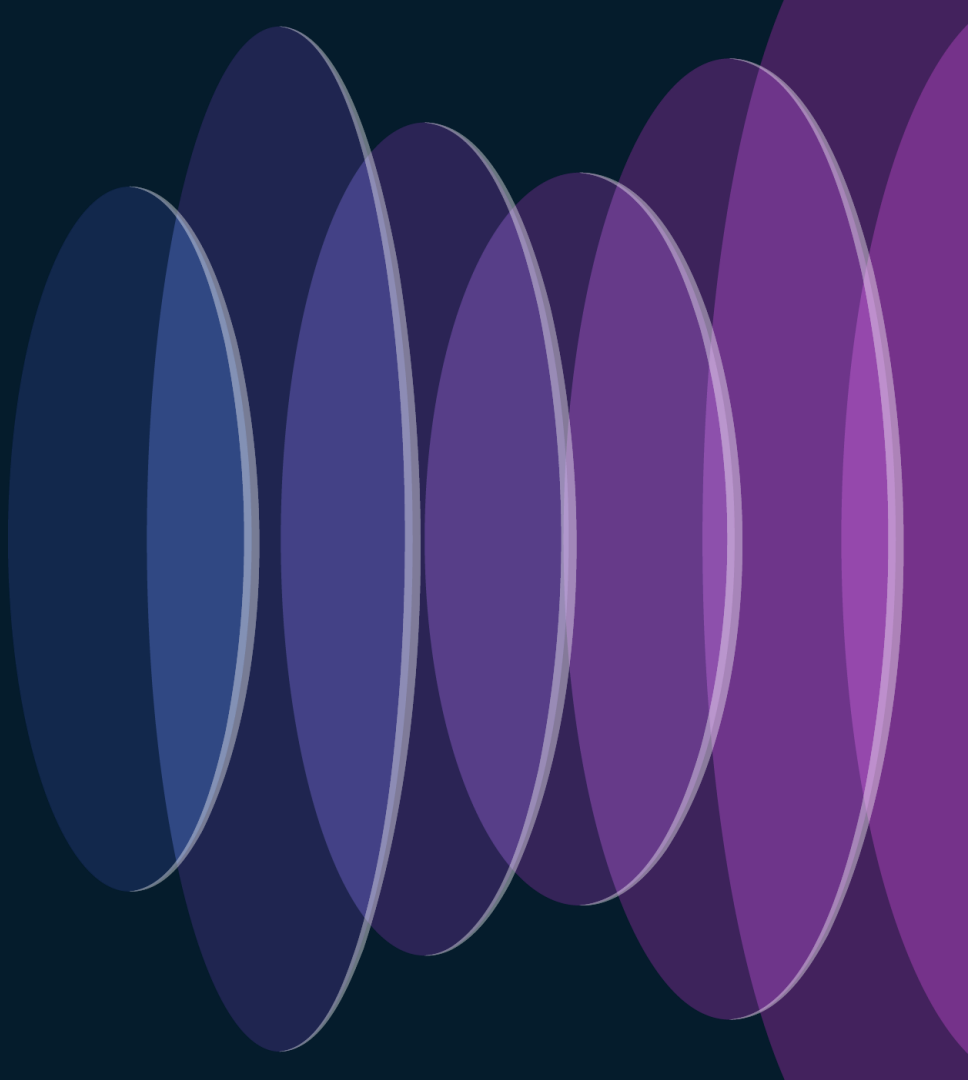




Cisco Vision for future Quantum Networks



Quantum Network Digital Twin for Quantum Network Planning, Modeling & Up Skilling and Training



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Cisco Quantum Network Simulator

- A software program that simulates aspects of quantum networking
- Models the physical properties of the hardware at various levels
- Simulates communication and network traffic
- Can provide accurate timing information for throughput, latency, and noise estimates

Cisco Quantum Network Emulator

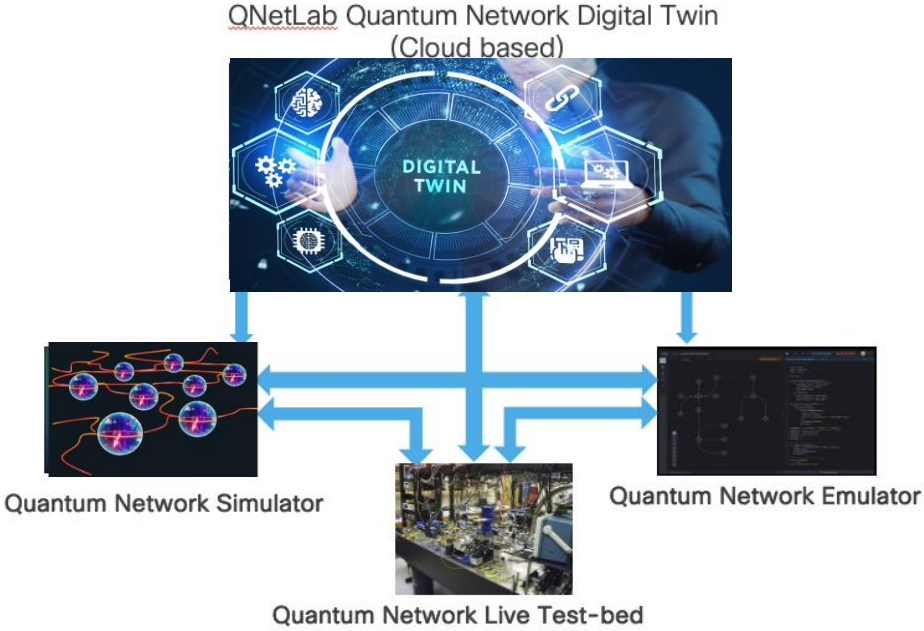
- A software system that mimics aspects of quantum network devices
- Uses simulation models “under the hood” to accurately mimic devices
- Uses time spoofing (if needed) to mimic processing or communication delays
- Can be used to develop control software and protocols

Cisco quantum network digital twin?

- An emulated quantum network “mirrored” to a physical quantum network
- The simulated models use real-time parameters from the physical network
- Real-time parameters are tracked and pushed to a database
- Can be used to perform networking monitoring, test new deployments, and accurately simulate

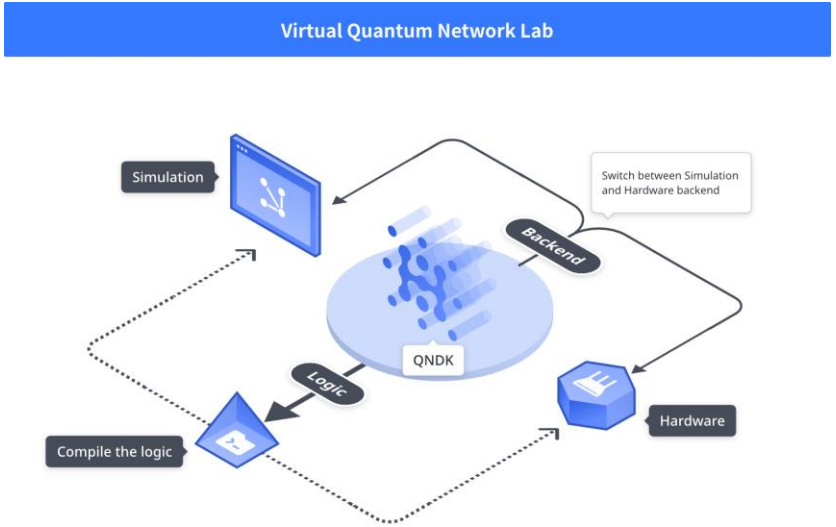
What is Cisco's Quantum Network Digital Twin QNetLab

- QNetLab Digital Twin
  - Quantum network planning tool
  - Quantum network simulation tool
  - Quantum network emulation tool
  - Feedback loop with the live Cisco quantum network test-bed
  - Up skilling and training tool for engineers
  - Support for
    - Entanglement based networking
    - QKD
    - Quantum computing interconnect networking
    - Quantum switching and routing

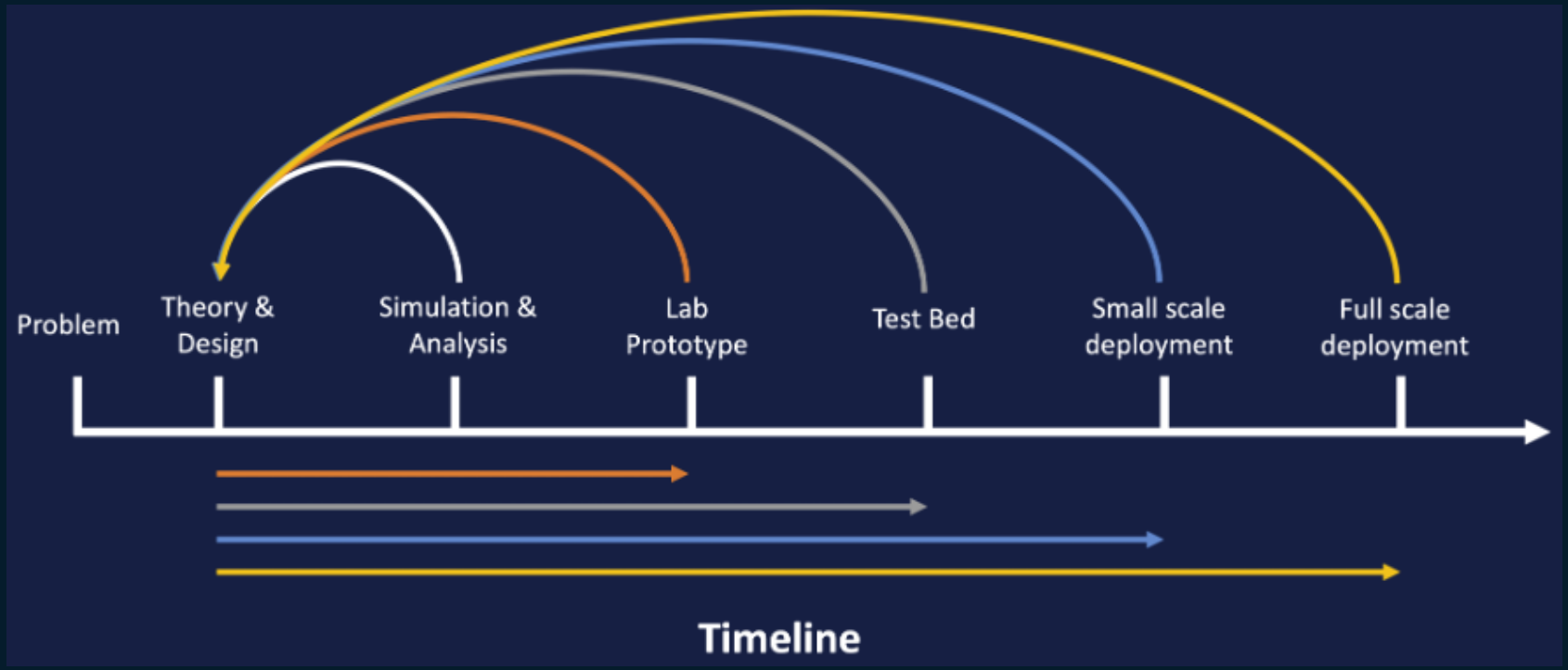


QNetLab Digital Twin

- Models the physical properties of the hardware
- Simulates communication and network traffic
- Provide access and real time feedback from a real-life quantum network test-bed
- Instantly apply simulated scenario in a real test-bed
- Model communication and network traffic
- Provides timing for throughput, latency, and noise estimates
- It is cloud based with a web based graphical user interface



QNetLab Digital Twin for the Lifecycle of Network Technologies



Using the QNetLab Digital Twin

1. Decide on Network Use Case, Protocol, Algorithm

Step 1: Decide

- What application do I want to simulate?
- QKD? Distributed Quantum Computing ? Entanglement Networking?
- What communication steps are needed to perform the application?
- Do I care about robustness? routing? timing?
- How do I measure correctness and efficiency?

Using the QNetLab Digital Twin

1. Decide on Network Use Case, Protocol, Algorithm

2. Define parameters

Step 2: Define

- The network topology (e.g., star, bus, mesh, etc.)
- The hardware parameters (e.g., fiber loss, switch frequency, etc.)
  - You can use parameters from real life test-bed
- Traffic model (e.g., Poisson, interval, etc.)
  - You can use parameters from real life test-bed

Using the QNetLab Digital Twin

1. Decide on Network Use Case, Protocol, Algorithm

2. Define parameters

3. Write code

Step 3: Code

- Choose from the various simulation & emulation libraries
- Write the protocol steps as detailed as desired
- Develop the network layers where necessary

Using the QNetLab Digital Twin

1. Decide on Network Use Case, Protocol, Algorithm

2. Define parameters

3. Write code

4. Run simulations

Step 4: Run

- Choose Time scale
- Run simulations of desired scenarios and topologies
- Record the results

Using the QNetLab Digital Twin

1. Decide on Network Use Case, Protocol, Algorithm

2. Define parameters

3. Write code

4. Run simulations

5. Analyze

Step 5: Analyze

- Plot the data and compare against state-of-the-art
- Analyze for hardware properties necessary to fulfil minimum performance requirements

Using the QNetLab Digital Twin

1. Decide on Network Use Case, Protocol, Algorithm
2. Define parameters
3. Write code
4. Run simulations
5. Analyze
6. Test on emulated + Real Test-bed

Step 6: Test

- Reserve emulation and real-life test-bed
- Setup emulation and real-life test-bed environment using APIs
  - Small scale version of simulated scenario
- Deploy your simulate scenario in a combination of emulated and real-life test-bed

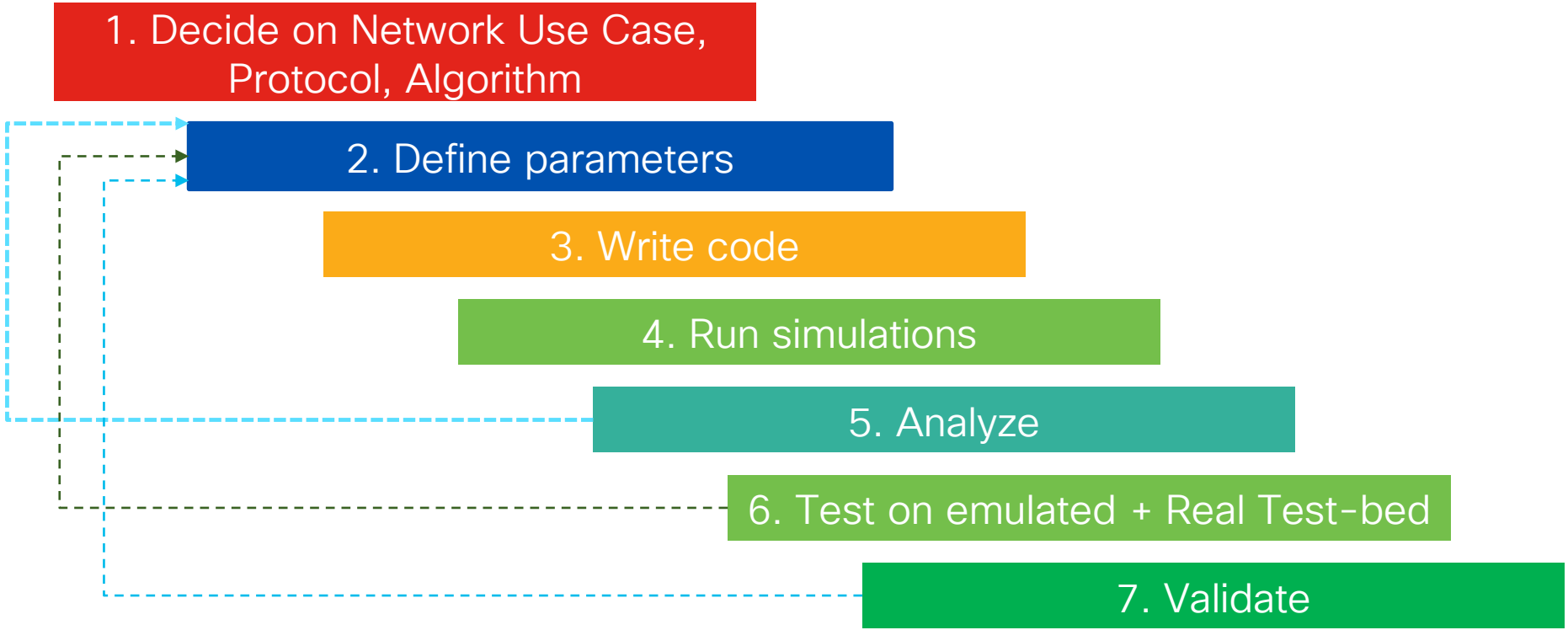
Using the QNetLab Digital Twin

1. Decide on Network Use Case, Protocol, Algorithm
2. Define parameters
3. Write code
4. Run simulations
5. Analyze
6. Test on emulated + Real Test-bed
7. Validate

Step 7 : Validate

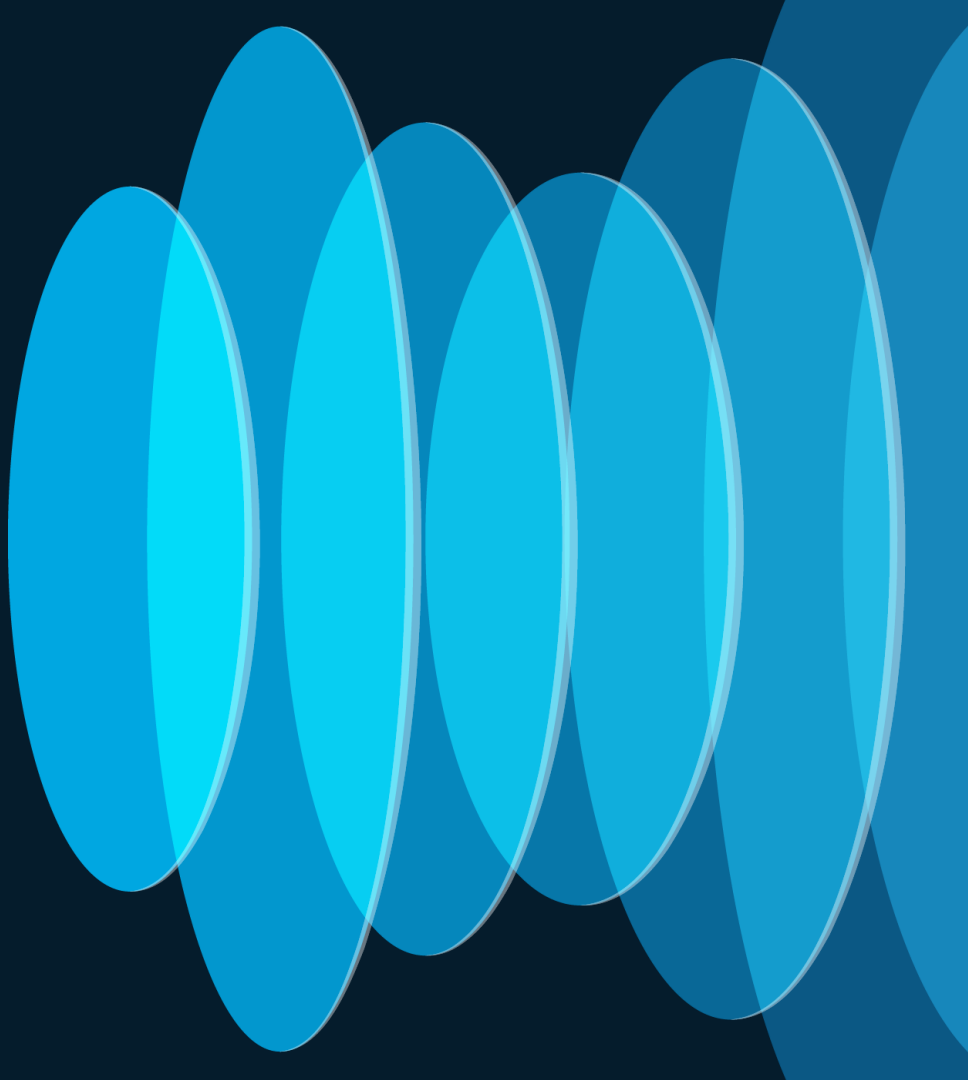
- Collected test-bed results
- Plot the data and compare against simulation
- Analyze for properties necessary to be adjusted in simulation

Using the QNetLab Digital Twin



QNetLab Digital Twin Mission

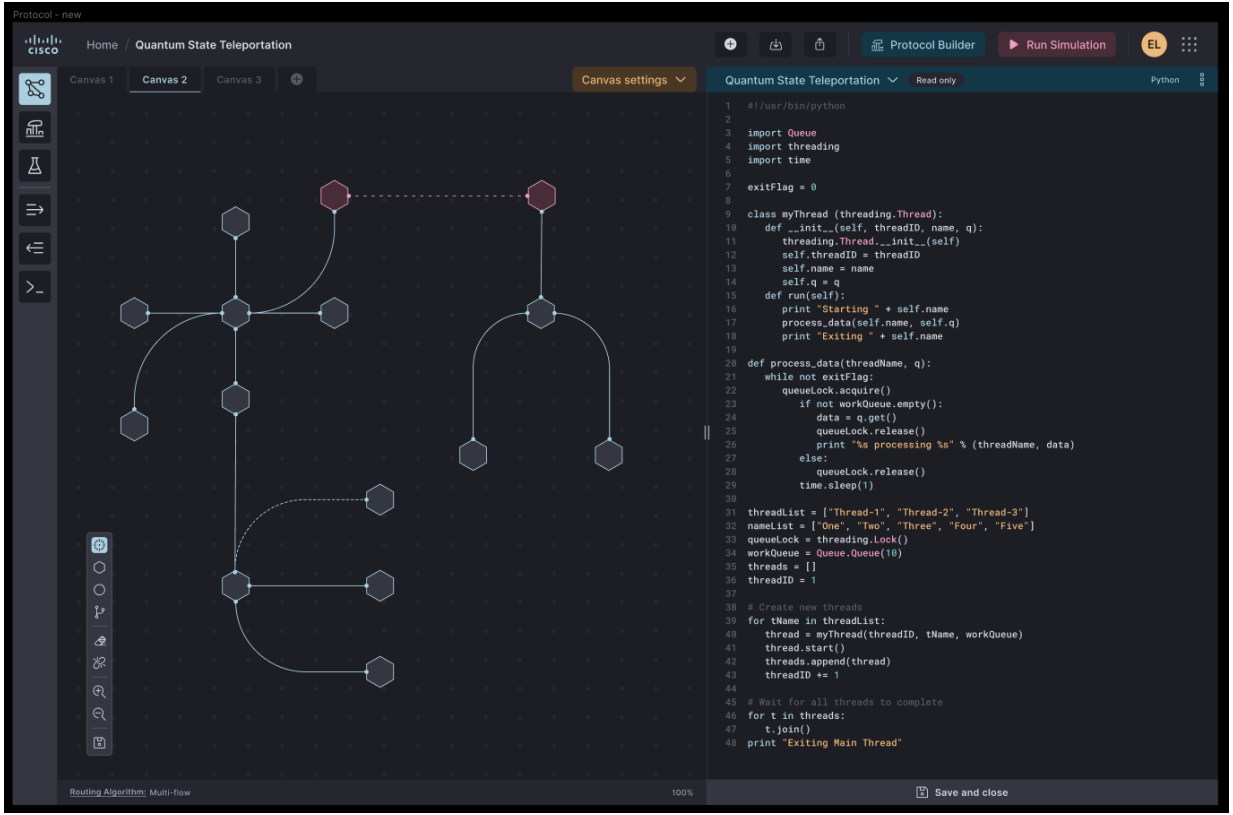
Make planning, operating and simulating quantum networks easy for everyone!



QNetLab Quantum Network Development Kit

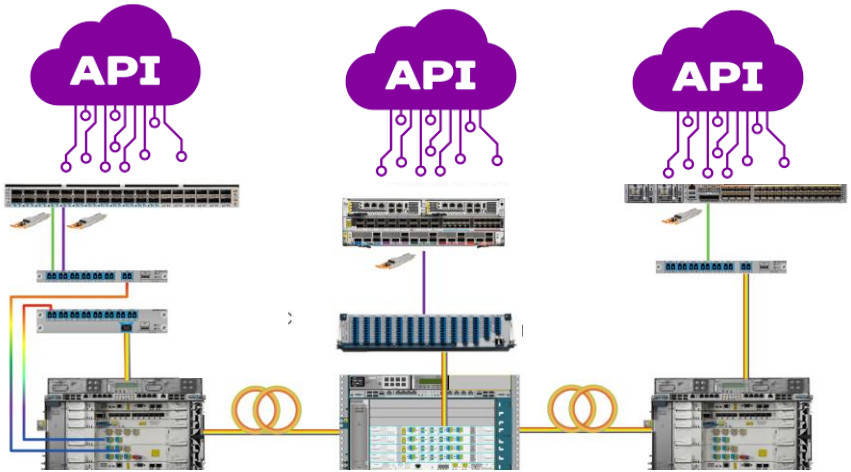
- A web based graphical user interface
- Provides pre-built simulations
- Runs simulations in the cloud
- Limits the amount of code writing
- Integrates various simulation engines

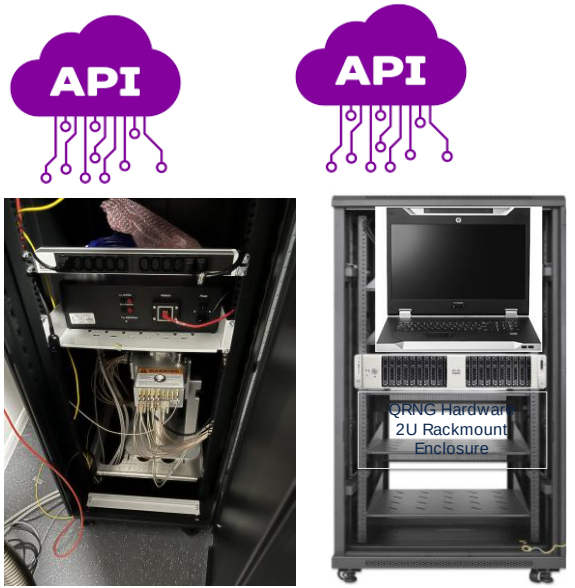
QNetLab Quantum Network Development Kit



Rela time Test-bed Connectivity

Connecting it to Test-bed and Emulation Environment

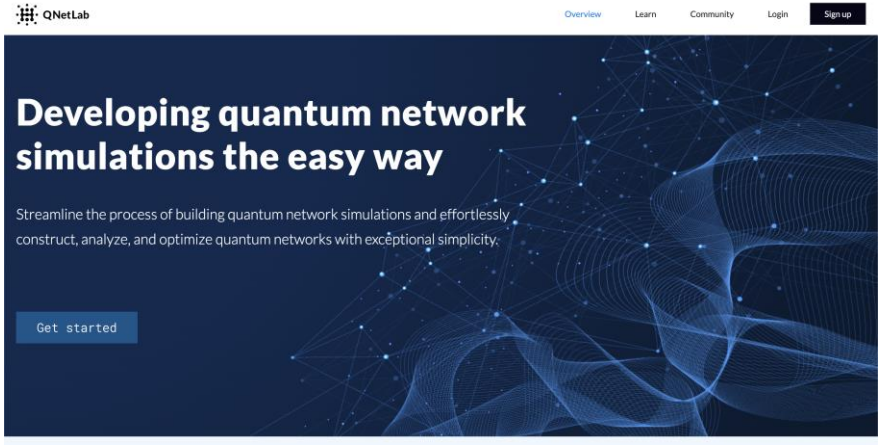


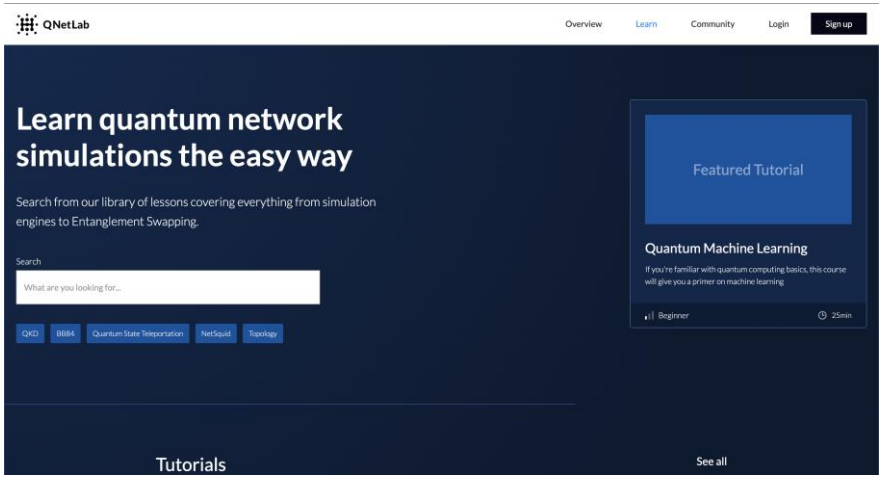


Community Building

- Creates a platform for resource sharing and learning
- Allows users to upload their simulations and collaborate

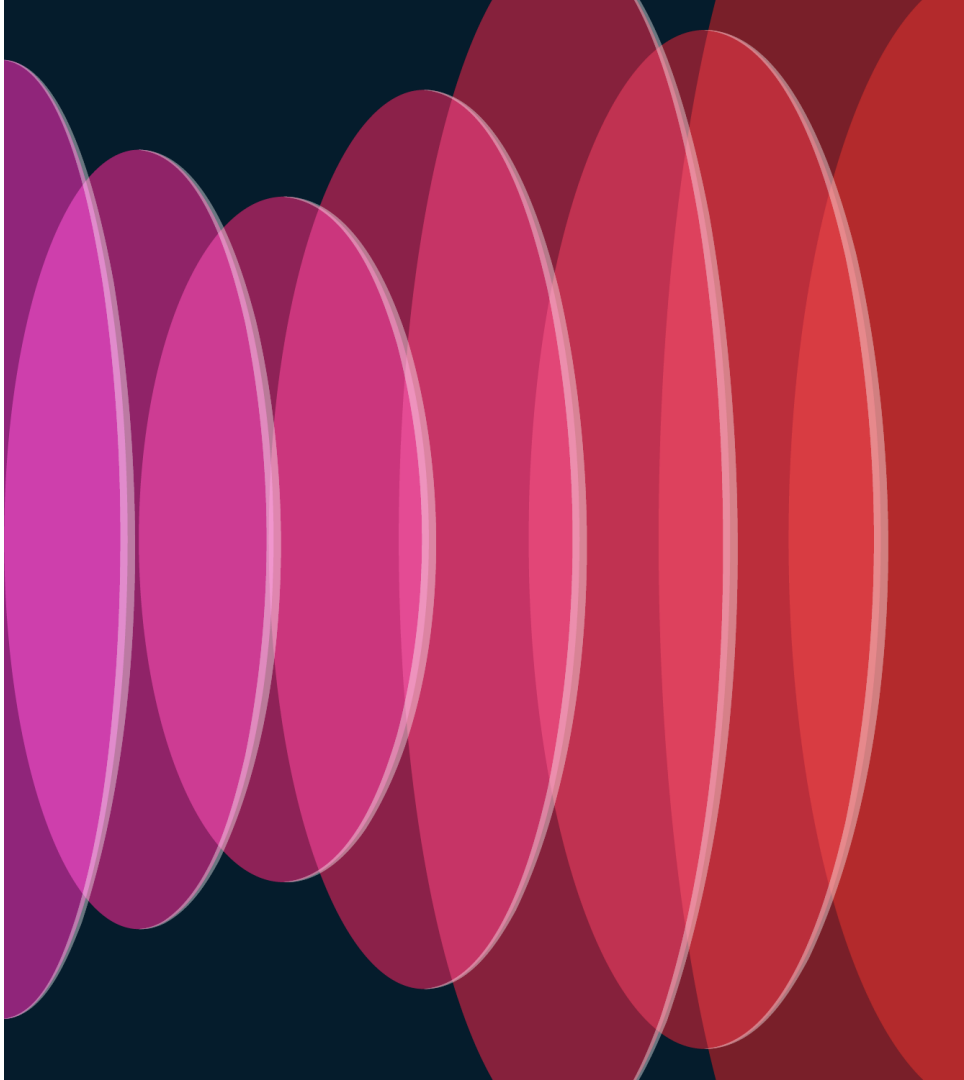
Get involved



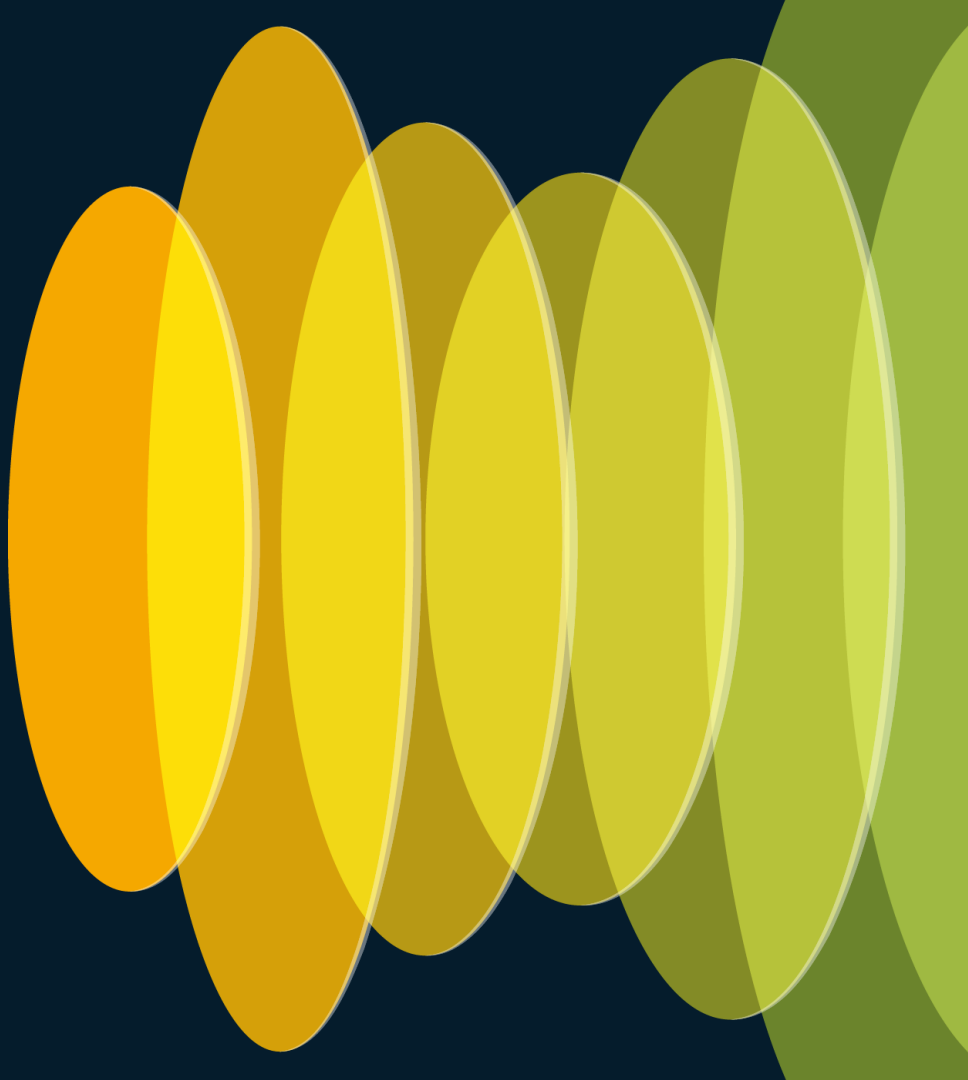


Demo 1

Digital Twin Quantum Network Development Kit



Quantum Random Number Generator



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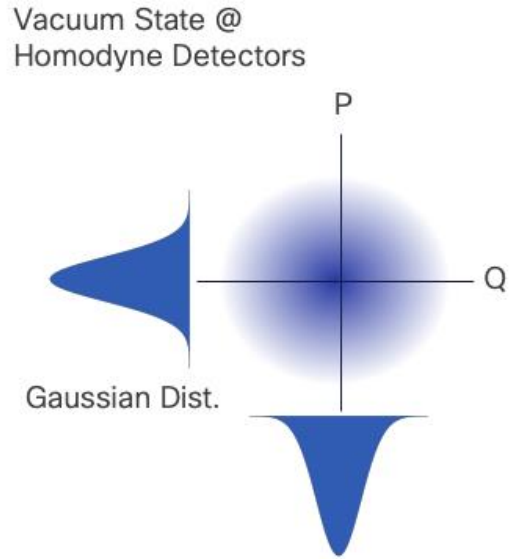
Cisco Quantum Random Number Generator (QRNG)

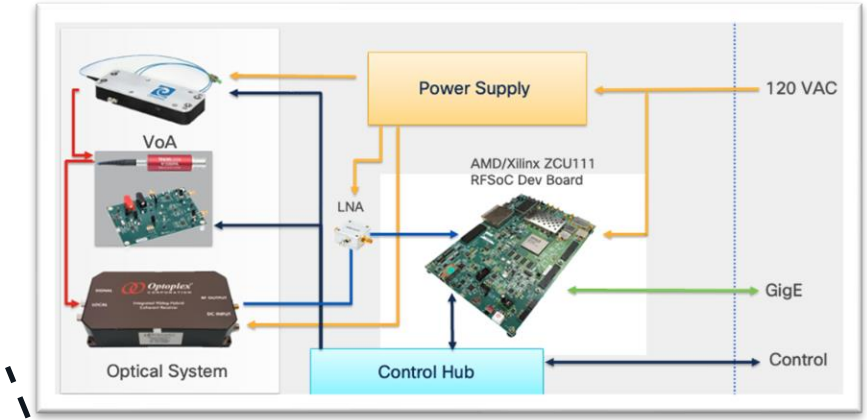
- Why QRNG is important
  - SW/algorithmic generated random numbers are not truly random (pseudo random)
  - QRNG can produce true random number
  - Validated by standard tests (e.g. NIST test)
- Application of QRNG
  - Any cryptography method/system needs QRNG to improve security
  - Simulation (Weather , Traffic)
  - Financial market
  - Gambling and betting

Where does the randomness come from?

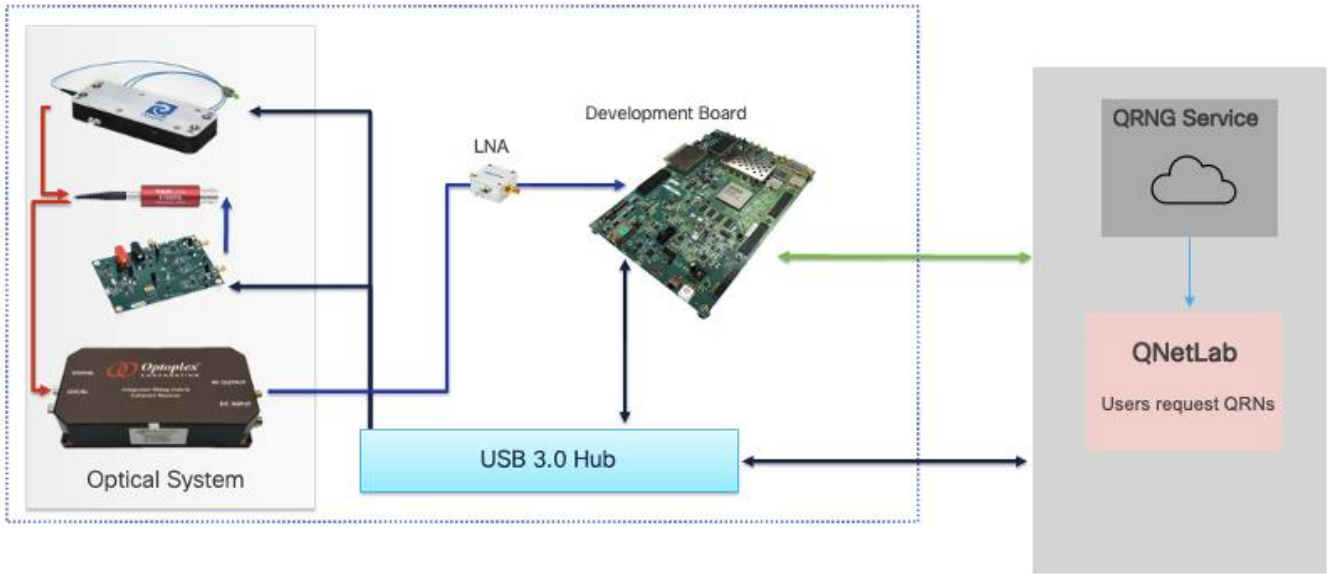
- Quantum noise of a vacuum signal follows Gaussian distribution in phase space
- By measuring one quadrature using a homodyne detector, raw Gaussian-distributed bits are generated
- We use “randomness extraction” to convert them to uniform random numbers



Cisco Quantum Random Number Generator (QRNG)



QRNG as a Service

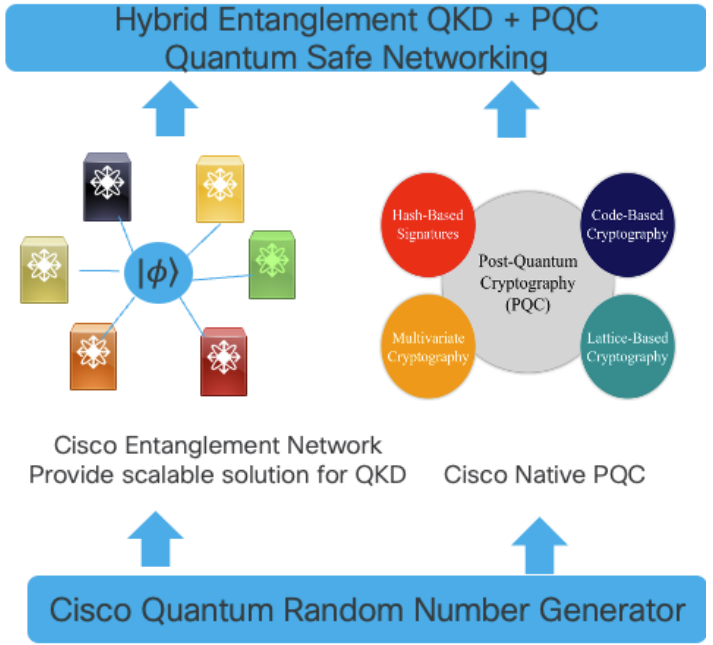


Quantum Network of the Future Supporting Quantum Safe Networking

- Any cryptography method/system needs QRNG to improve security

- Existing cryptography systems require random number
  - Existing random number generators are pseudo random
    - pseudo random numbers are repeatable/predictable
  - QRNG utilizing quantum uncertainty is able to generate true random number

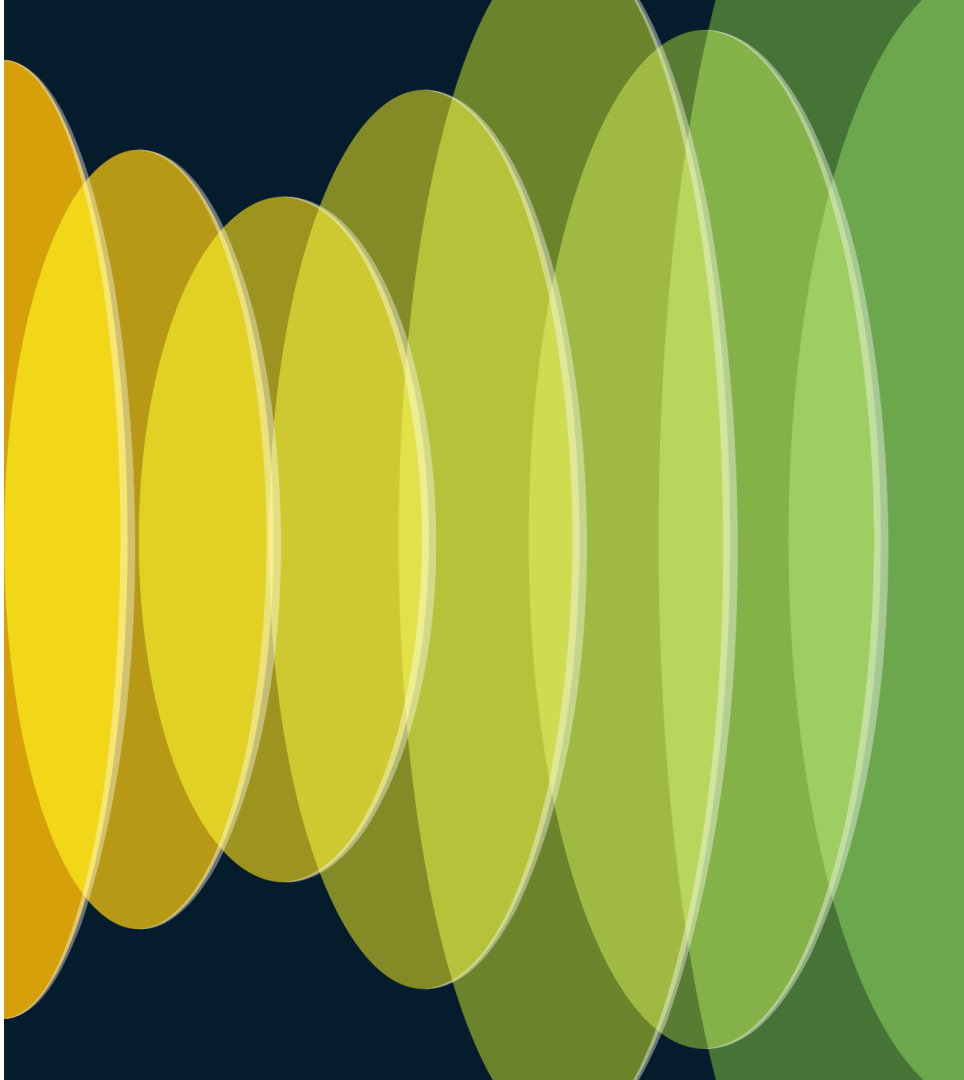
- Future Networks will require new quantum computing proof security
    - Two possible solutions
      - Quantum cryptography
      - Post quantum cryptography

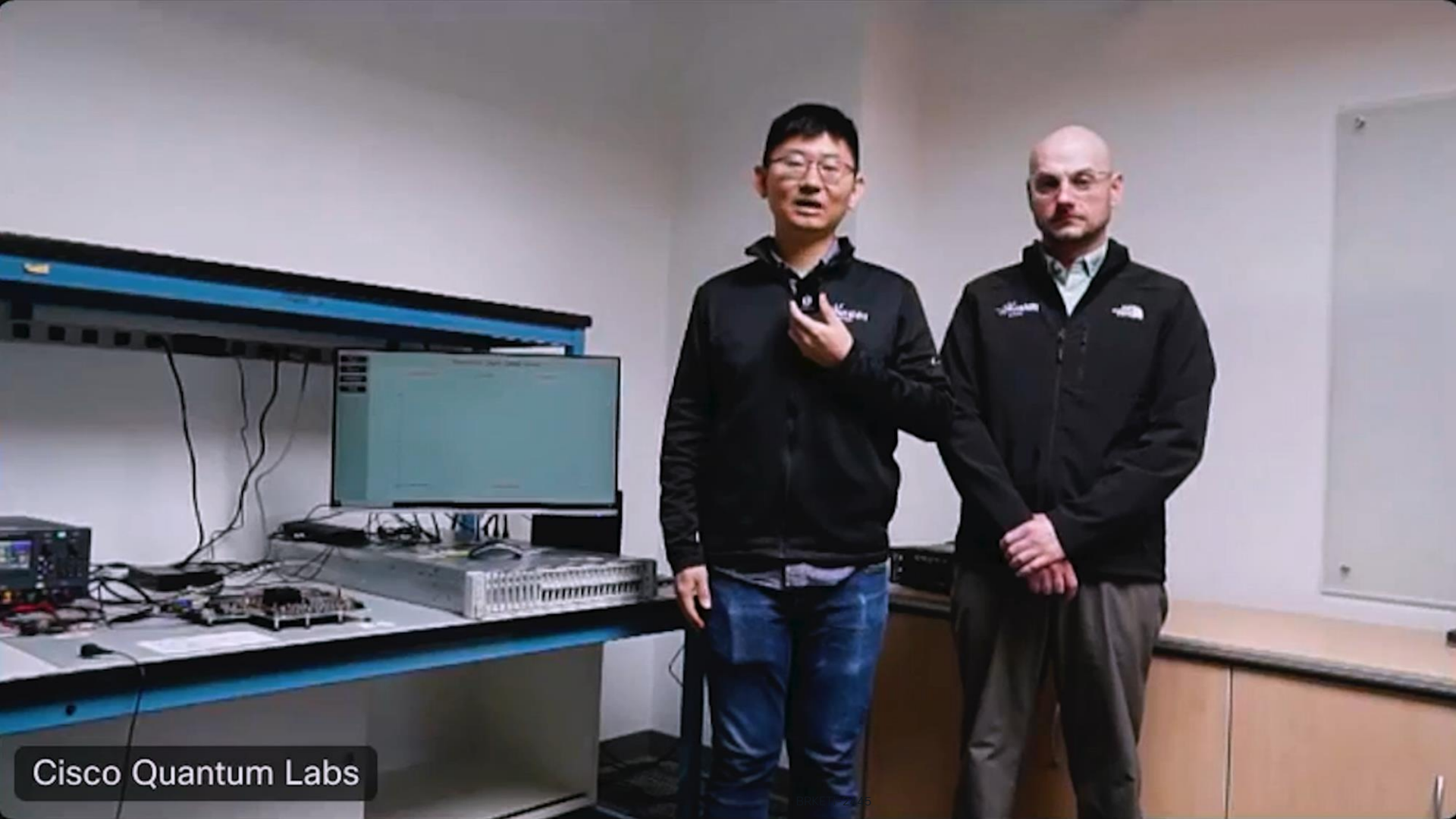


Demo 2

Quantum Random Number Generator

Using Real Life Test-bed




Cisco Quantum Labs

Thanks to the Cisco Quantum Research Team

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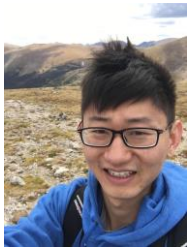
Reza Nejabati

Hassan Shapourian



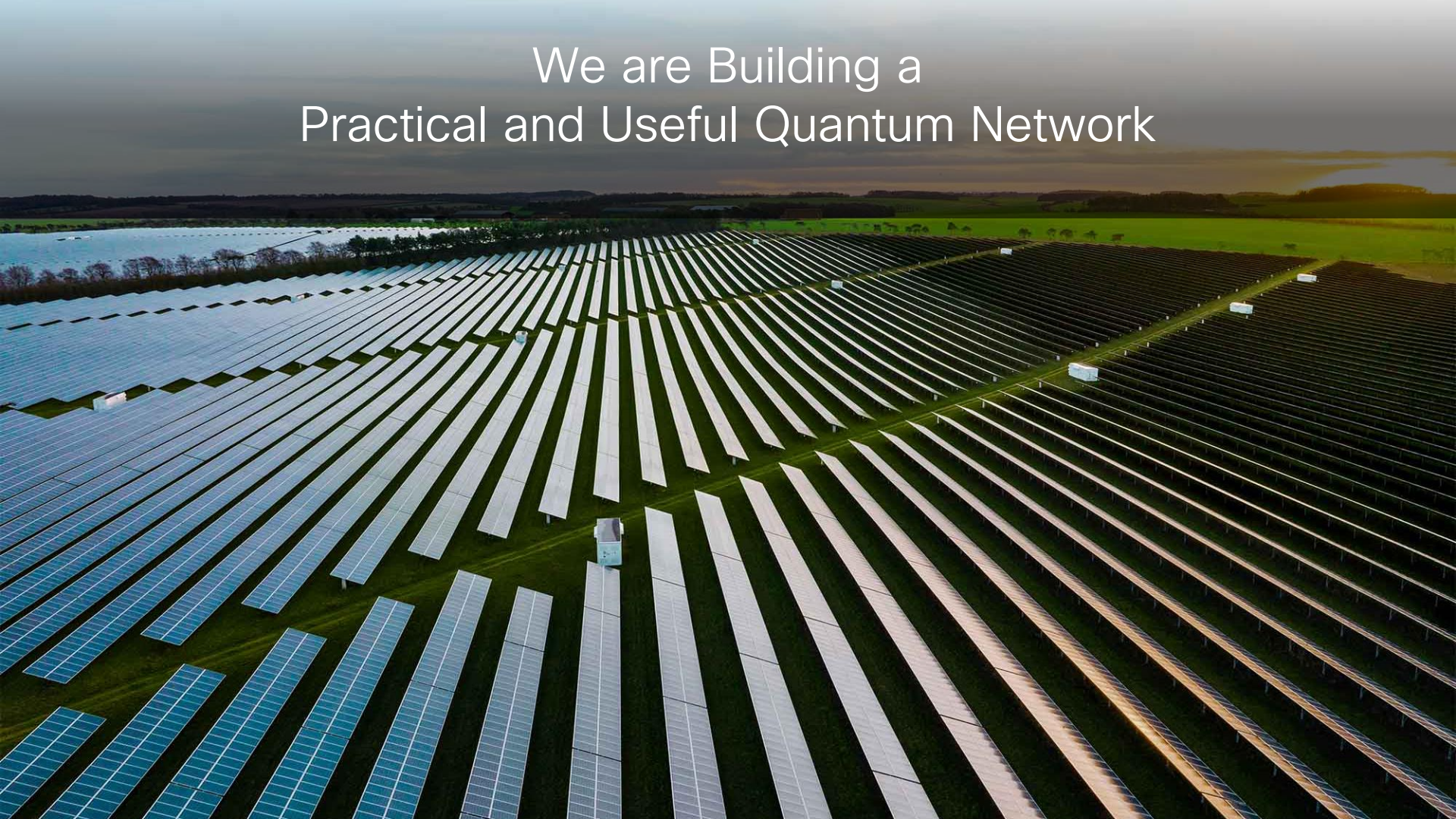
Jiapeng Zhao

Eneet Kaur

Michael Kilzer

Stephen DiAdamo

We are Building a Practical and Useful Quantum Network



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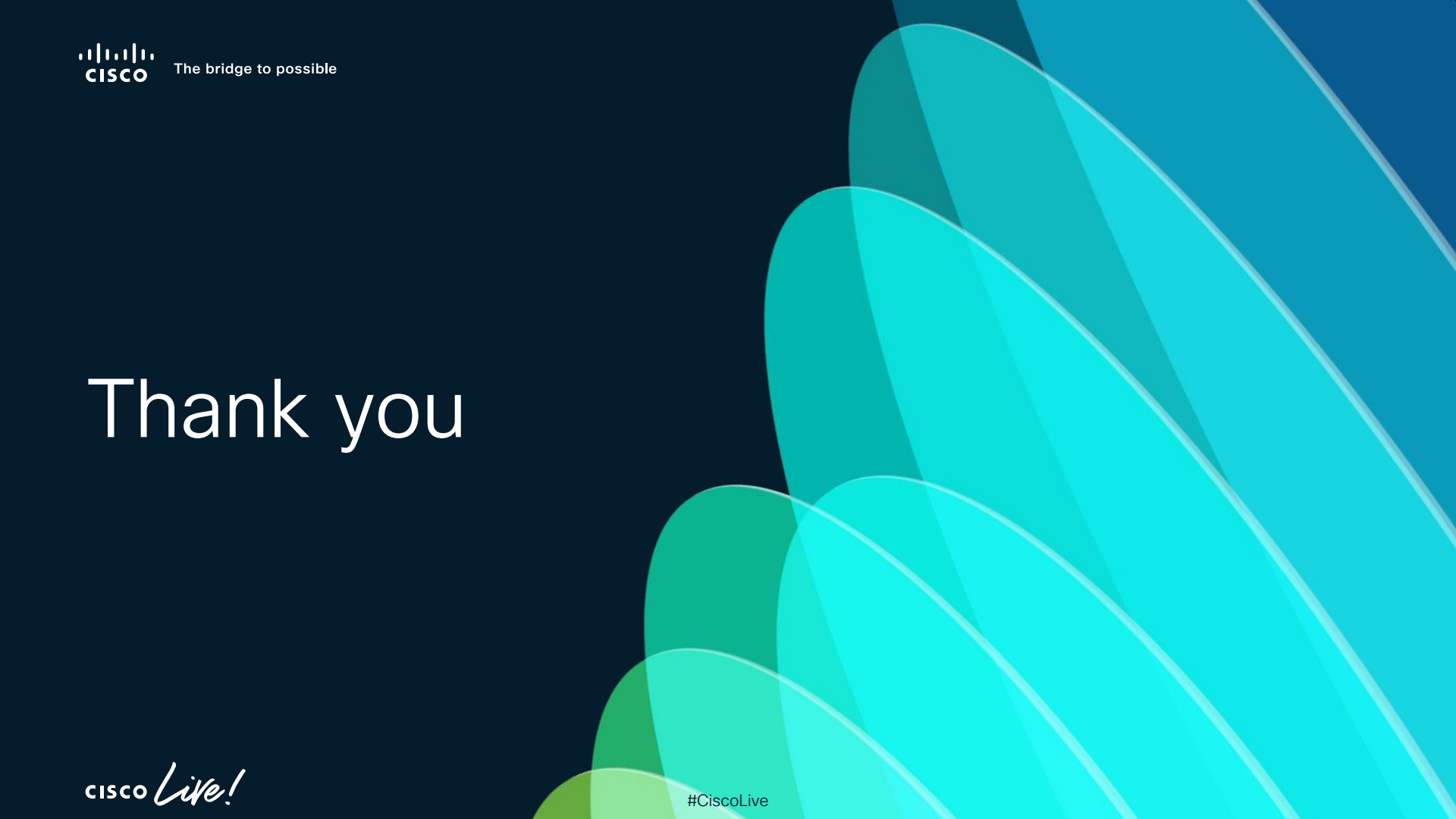
Contact me at: rnejabat@cisco.com


The bridge to possible
Thank you
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