Cisco Quantum Network Vision & Strategy

Towards a Practical and Useful Quantum Network

Dr. Reza Nejabati
Head of Quantum Research
POSETI-1402

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by CISCO

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Products		Cisco	Cisco	Cisco	Cisco
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2

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
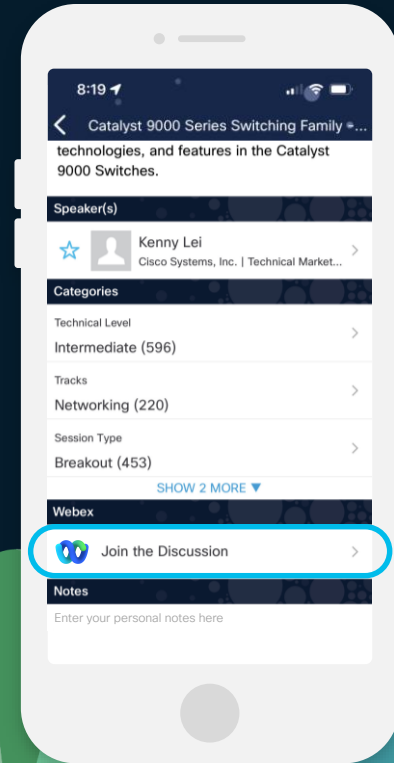
Cisco Webex App

Questions?
Use Cisco Webex App to chat
with the speaker after the session

How

1. Find this session in the Cisco Live Mobile App

2. Click "Join the Discussion"

3. Install the Webex App or go directly to the Webex space

4. Enter messages/questions in the Webex space

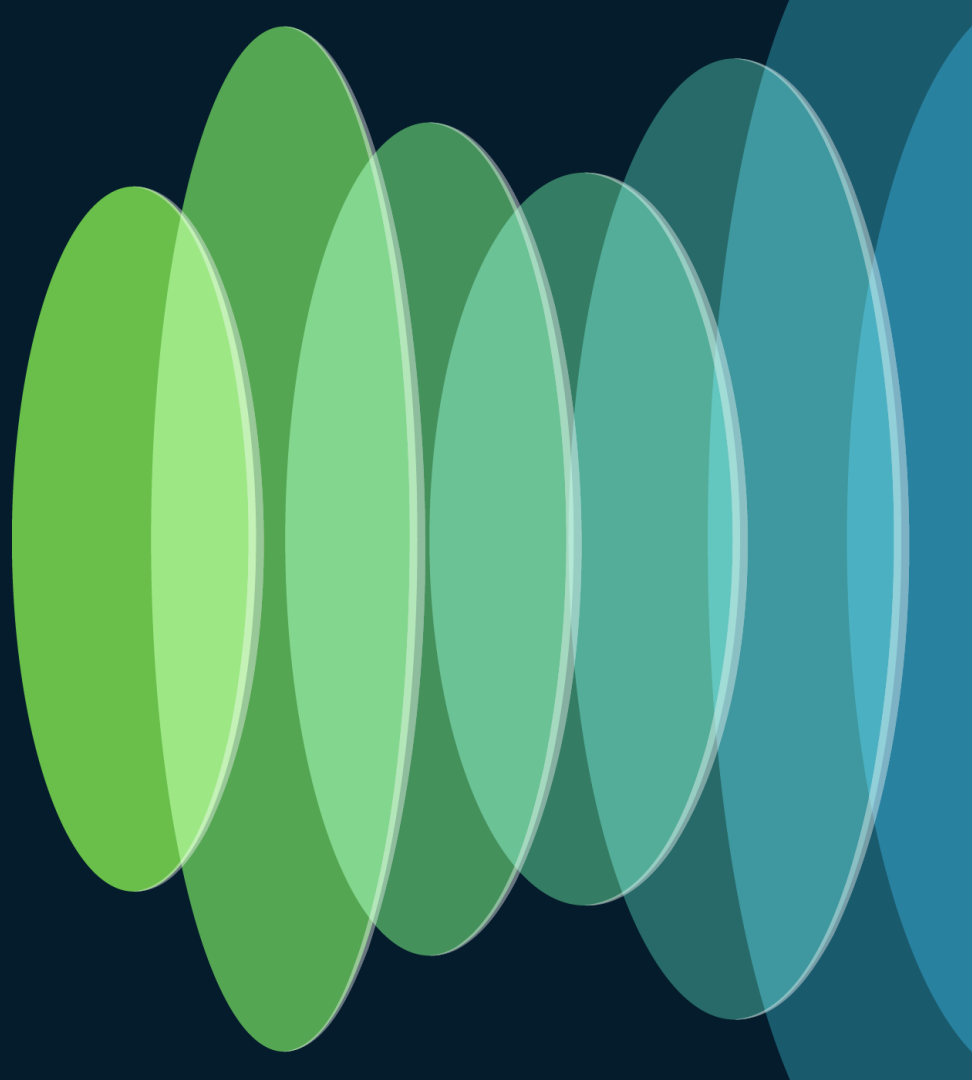Webex spaces will be moderated
by the speaker until June 7, 2024.

Agenda

- Harnessing Power of Quantum

- Quantum Network

- Scalable Quantum Computing

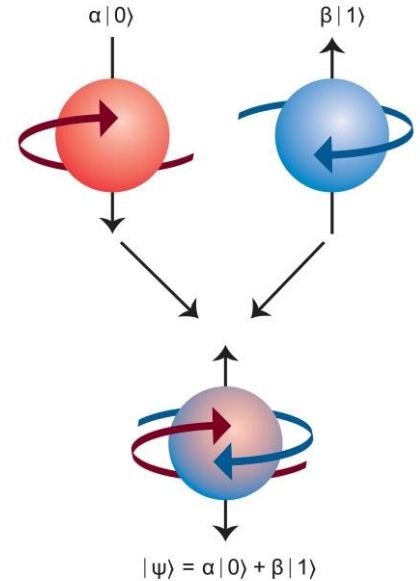- Quantum Network Supporting Next G (6G)

- Quantum Network Digital Twin

Harnessing Power of Quantum Mechanics

A Cisco View

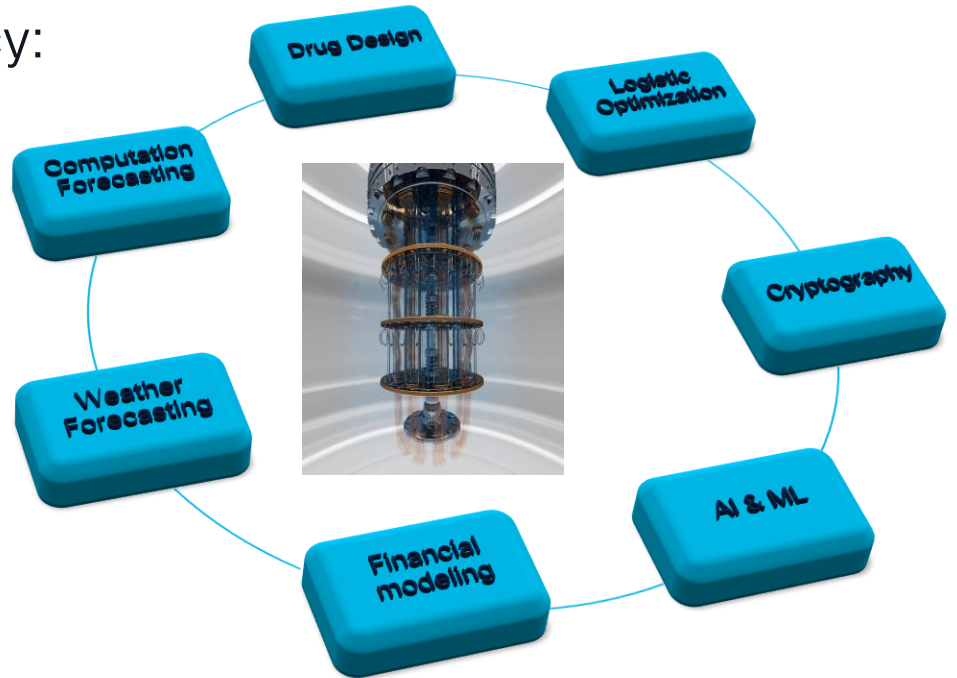CISCO *Live!*

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

$\alpha|0\rangle$

$\beta|1\rangle$

$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

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

Drug Design

Logistic Optimization

Computation Forecasting

Cryptography

Weather Forecasting

AI & ML

Financial modeling

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

| Timing | Acceleration | Magnetic Field | Imaging |
| Rotation | Temperature | Electric Field | Detection |

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
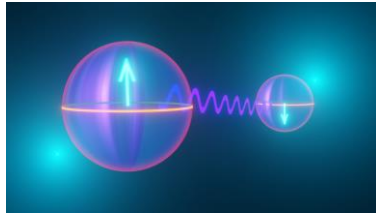
Harnessing Power of Quantum Mechanics Teleportation

- **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
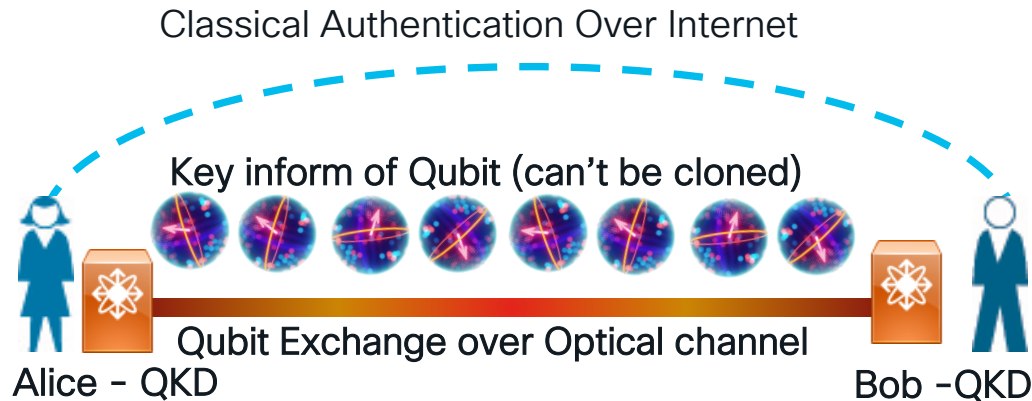 - **However receiver can not reconstruct A without help of sender**

A   B   C A   B
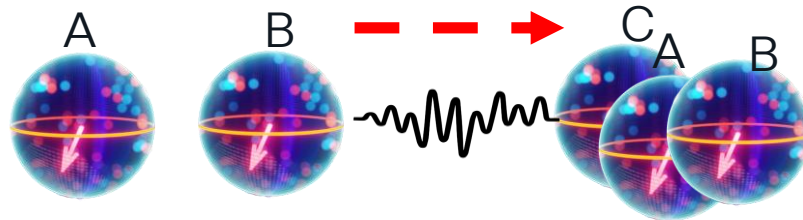
Quantum Supremacy

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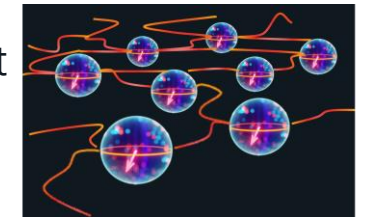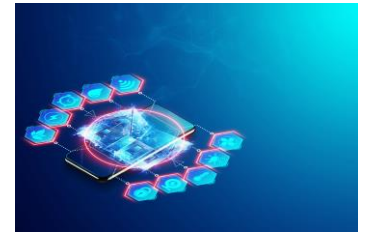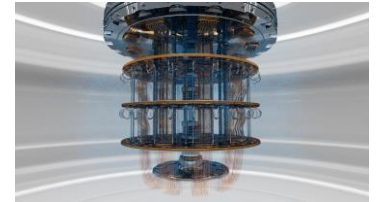
Today's Commercial Quantum Networks State-of the-Art

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

Classical Authentication Over Internet

Key inform of Qubit (can't be cloned)

Qubit Exchange over Optical channel

Alice - QKD

Bob -QKD

- 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**

Quantum Network A Cisco Vision
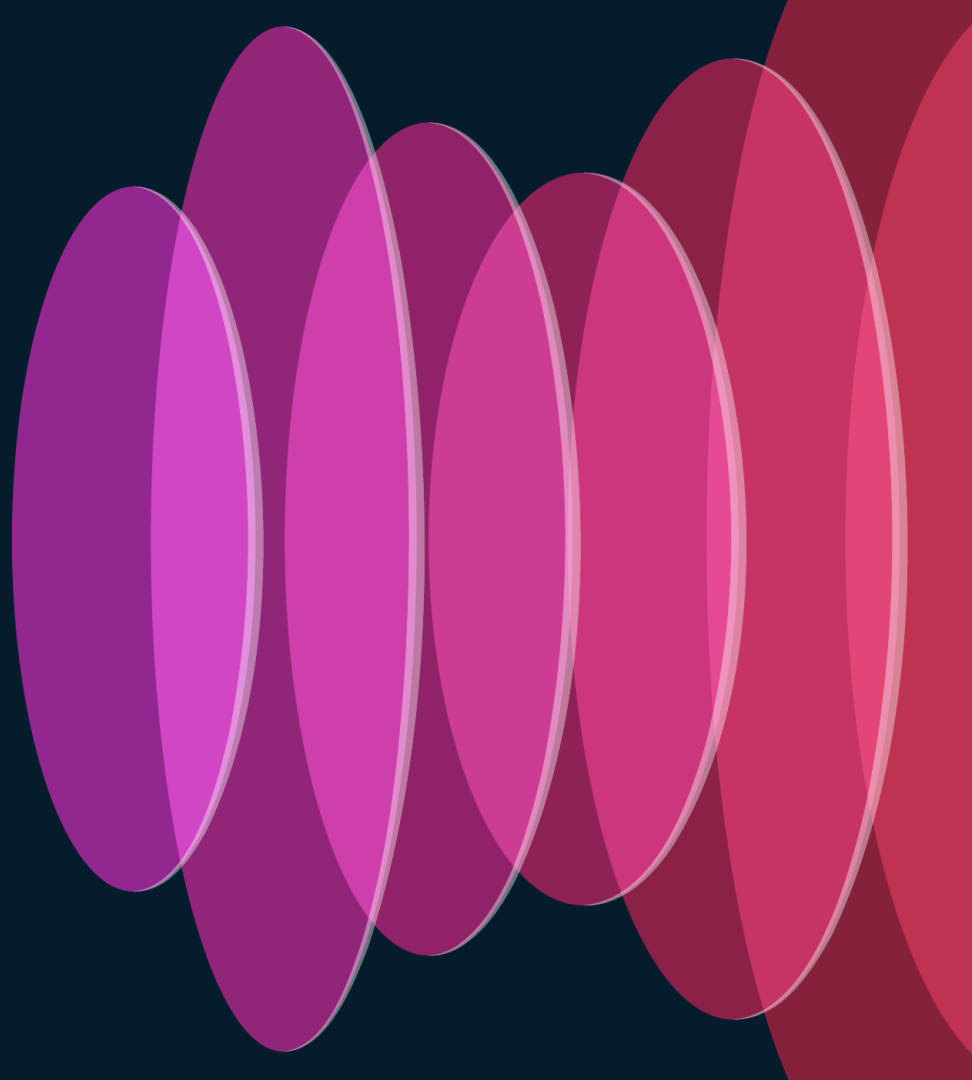
Cisco Quantum Network Vision

Quantum Security

Cisco Quantum Network

Quantum Cloud Computing

Quantum Computing

Multi-User & Multi-Tenant

Quantum Data Center

Quantum Sensing

Quantum Network
Dynamic, Entanglement, Co-existence

Distributed Quantum Sensing

Quantum Network Control
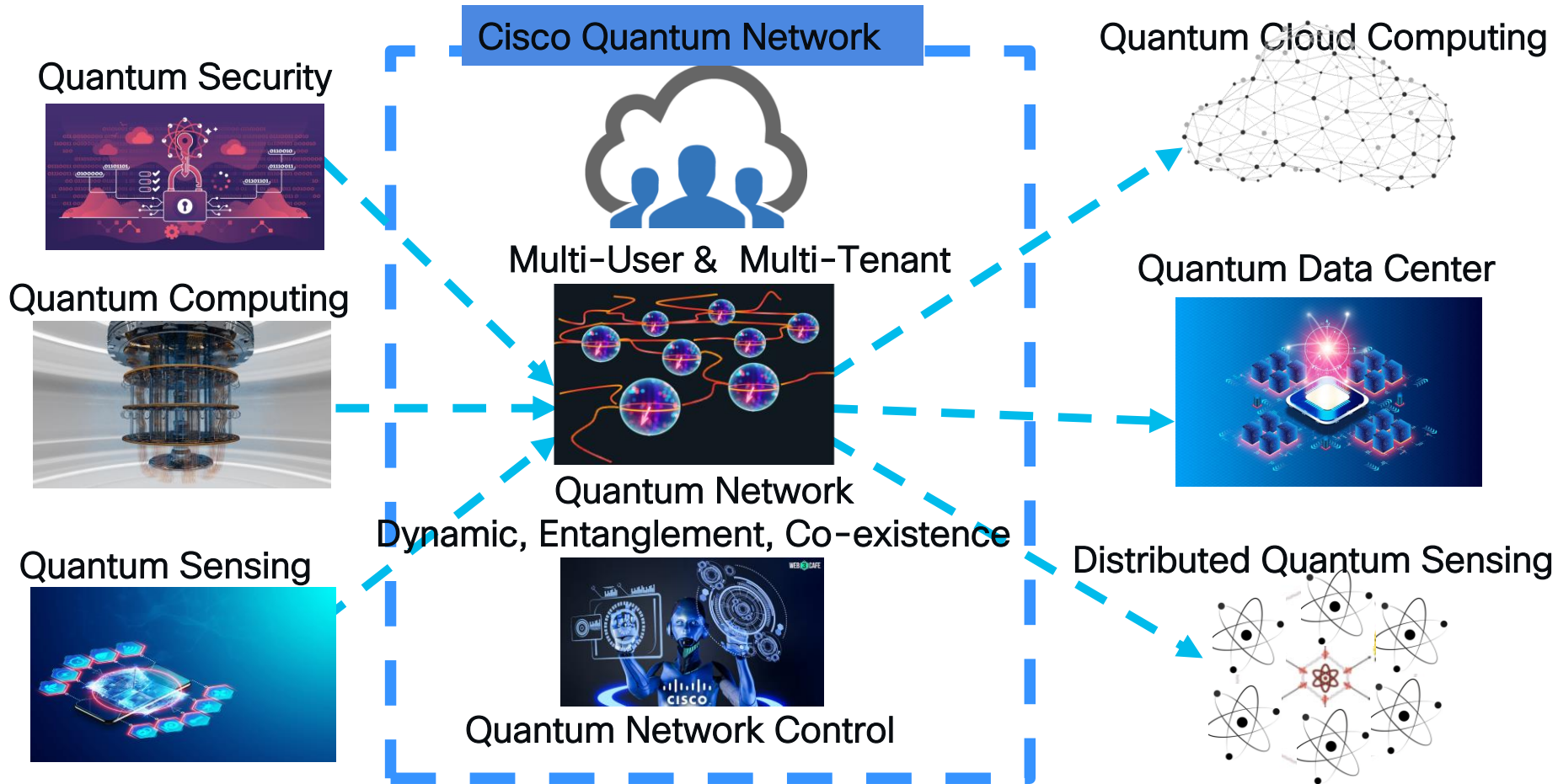
Cisco Quantum Network Vision

- ## 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
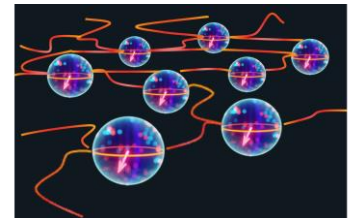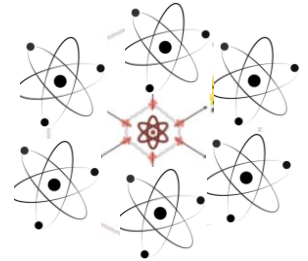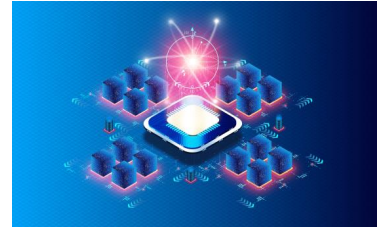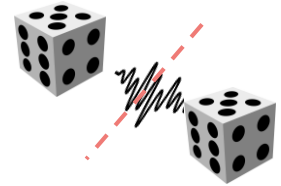
Harnessing Power of Quantum Entanglement

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

Entangled Photons

EPR Source

Alice Measurement

Bob Measurement
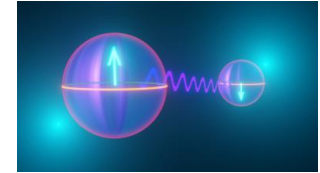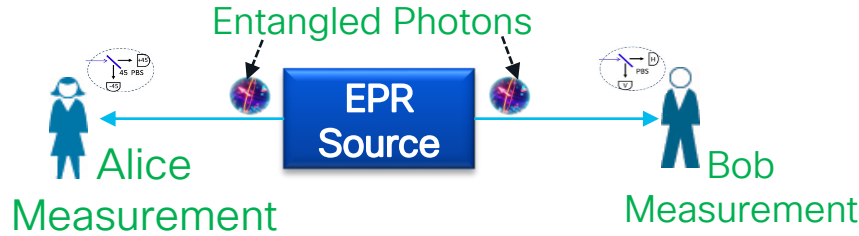
Entanglement Communication layer

Laser Pump

Entangled Photons

Entangle Distribution Network

Nonlinear Material [Crystal]

Quantum Switch

$|\phi\rangle$
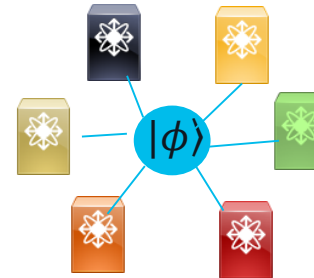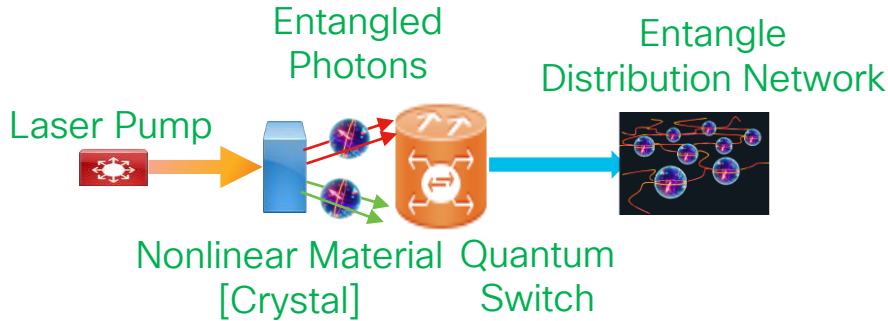
Entanglement Physical layer

Cisco is Building a Dynamic Quantum Entanglement Network Fabric

Cisco Quantum Entanglement Network Fabric

Entanglement Distribution Network Protocol Stacks

Quantum Switch · *Quantum Measurement* · *Entanglement Source* · *Entanglement Swapping* · *Quantum Memory*
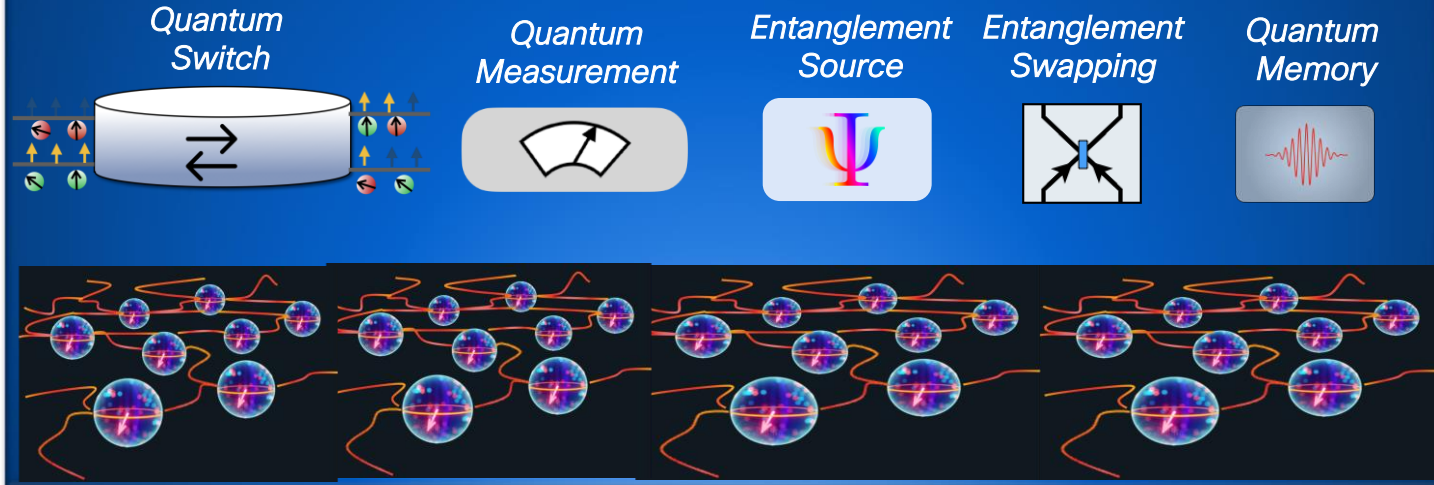
Cisco's Quantum Enabled Switch

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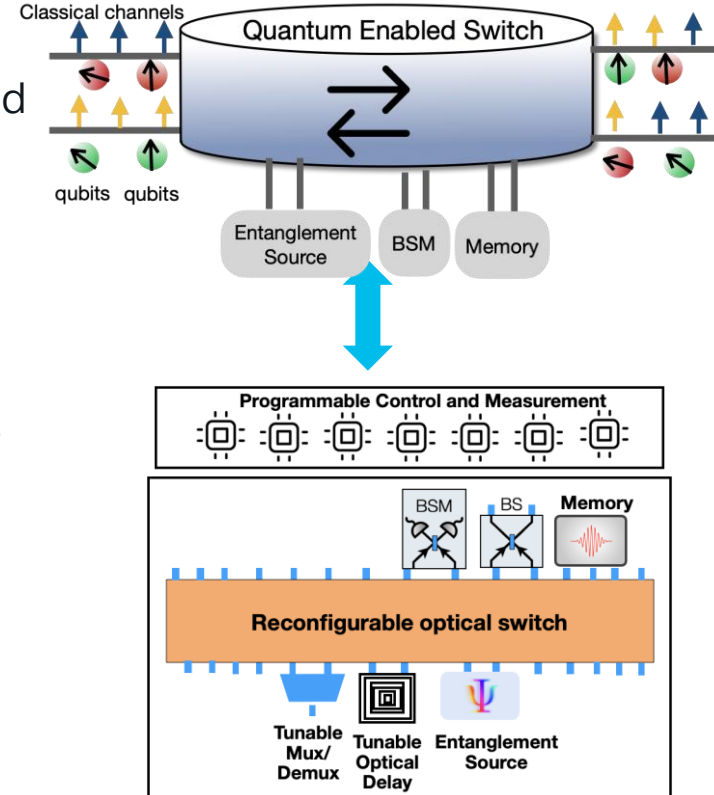
Building Logical Quantum Network : Towards Multi-Tenant and Scalable Quantum Networking

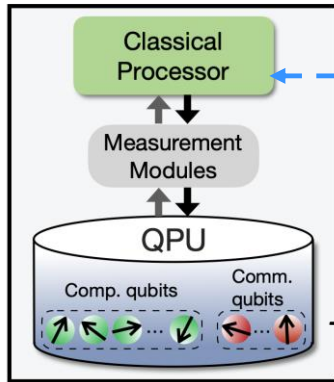# Quantum Network For Scalable Quantum Computing
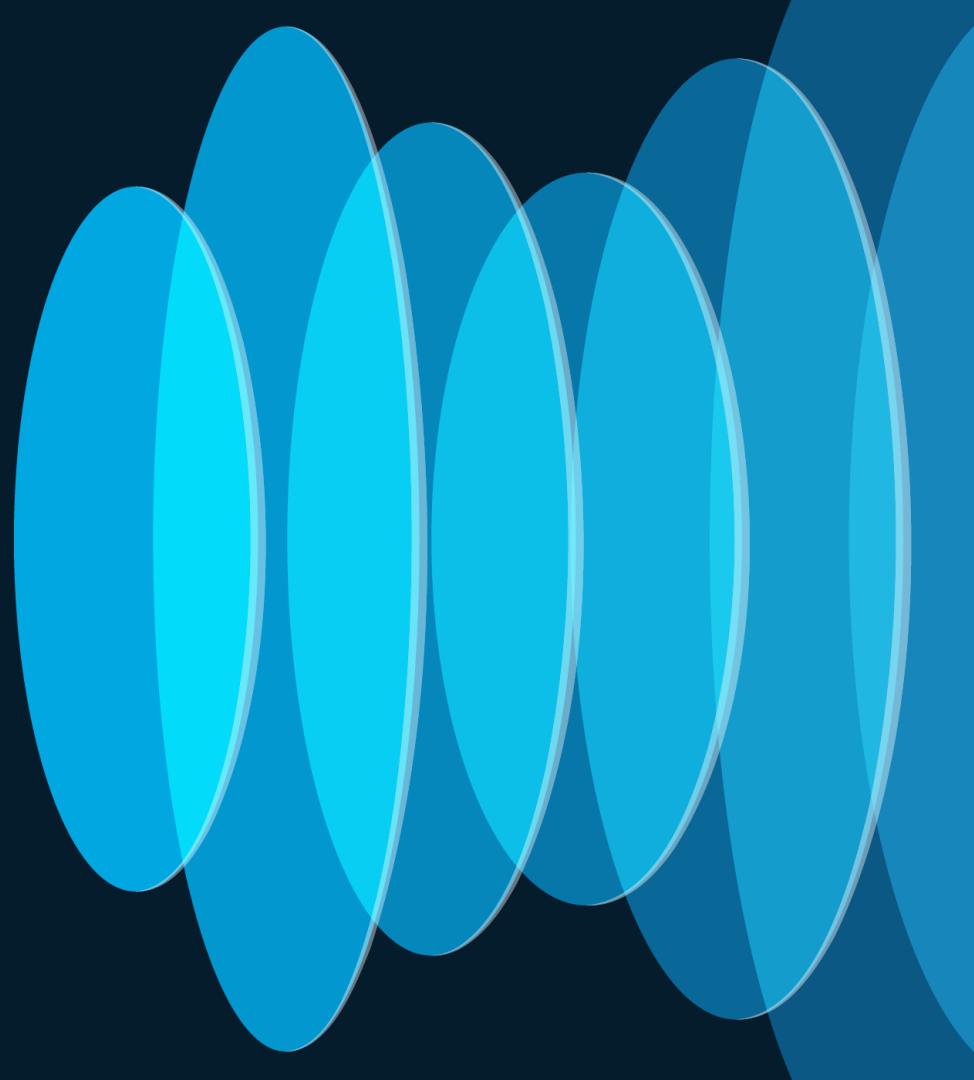
Quantum Data Centers

- 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
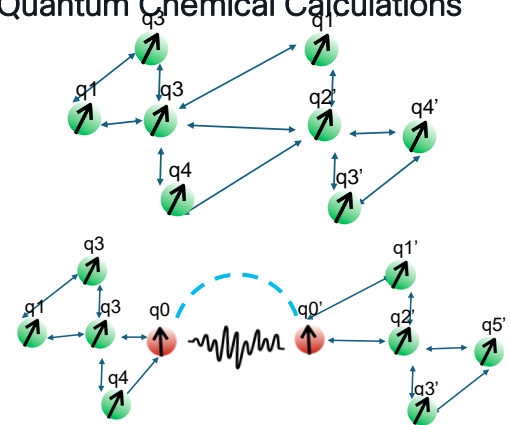 - Create a scalable quantum computing by networking large number of small processor
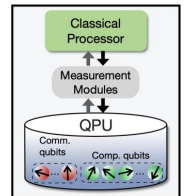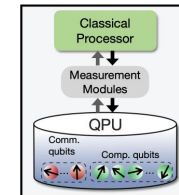
Distributed Quantum Computing

Quantum Application
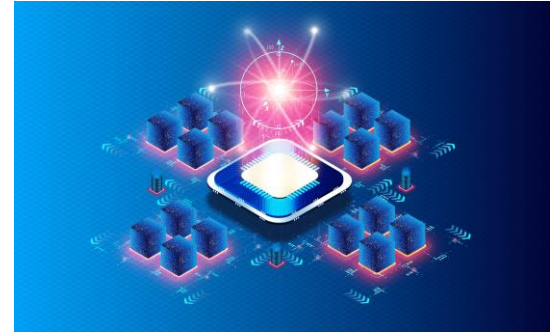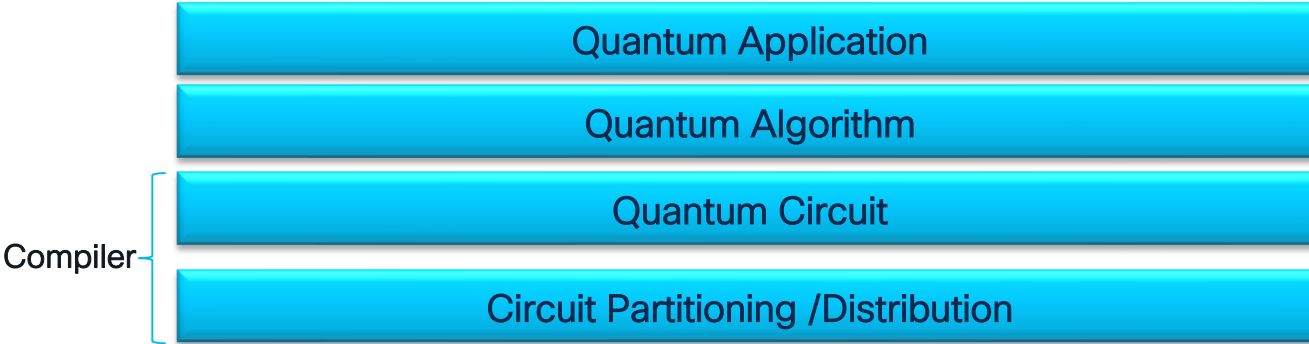
Drug Design

Quantum Algorithm
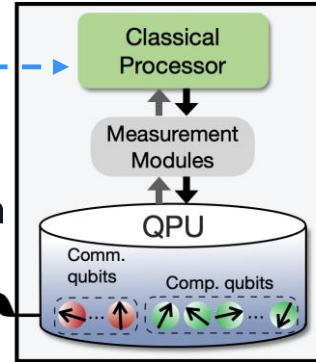
Quantum Chemical Calculations

Compiler

Quantum Circuit

Circuit Partitioning /Distribution

Classical communication

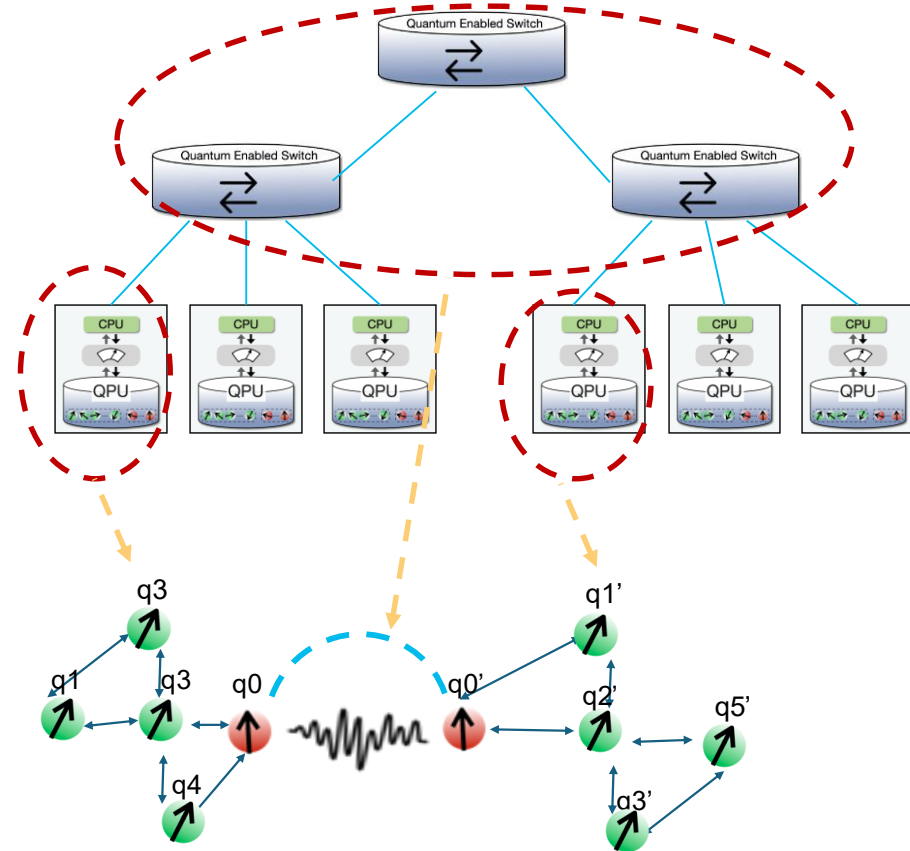Quantum Communication
Entanglement

Quantum Computer

Quantum Computer

Quantum Computer
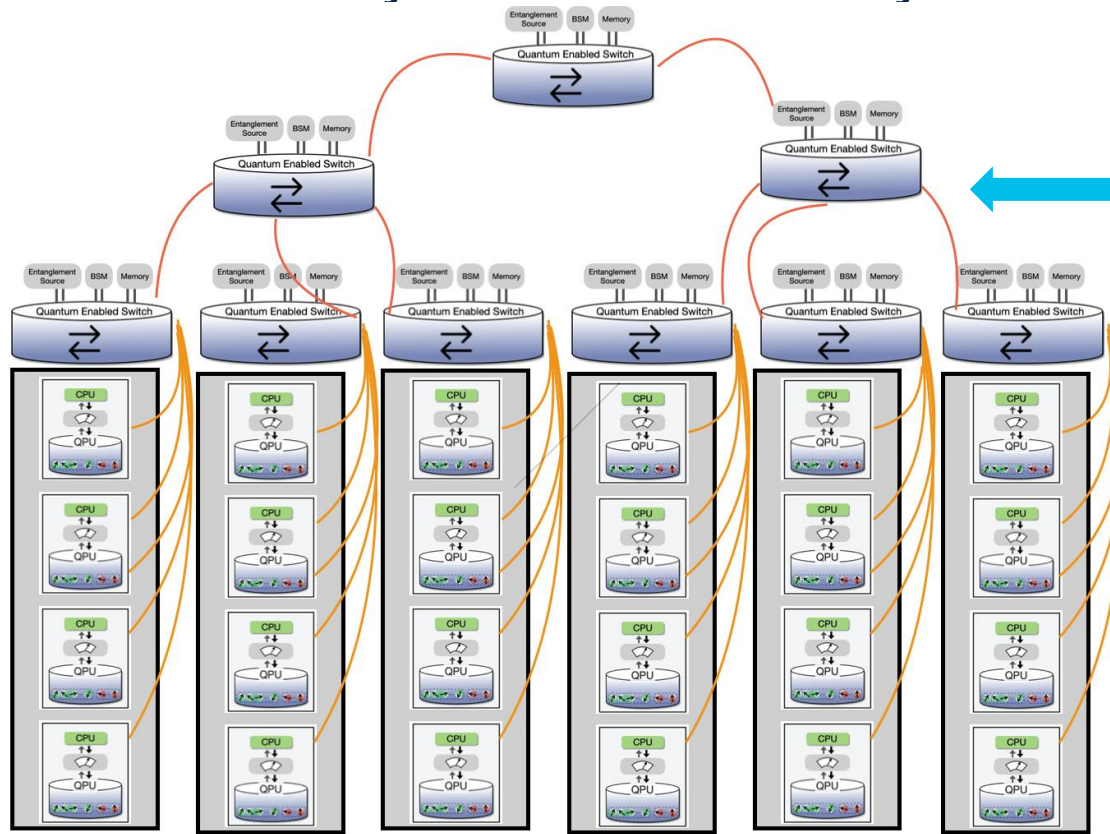
Quantum Computer

Quantum Data Center Architecture

- Challenges
  - Decoherence time of Qubits
  - Link Loss
  - Number of Processing Qubit VS Communication Qubits
  - Entanglement Fidelity
  - Network-aware Quantum Circuit Partitioning

# Cisco Vision for Quantum Data Center Architecture Techno- Economy and Scalability Considerations

Network Type 2:
Inter Rack Network

Network Type 1:
Short distance Intra Rack Network

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
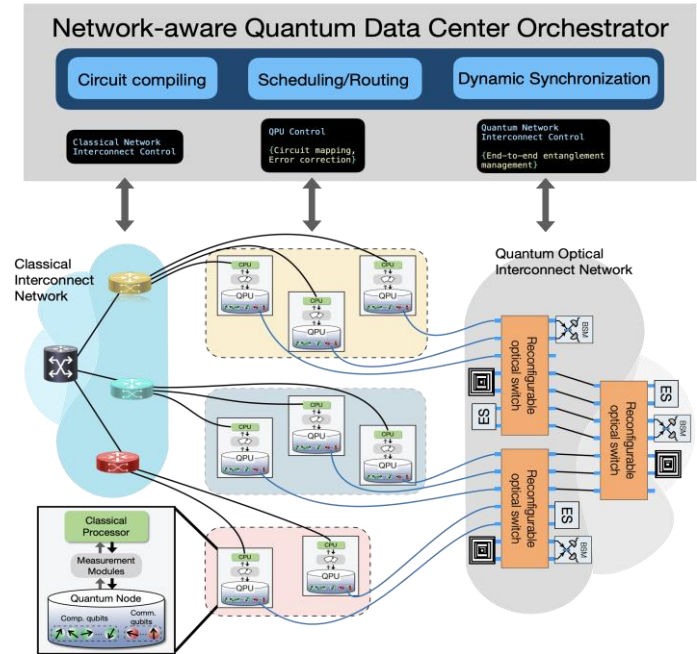
Quantum Network of the Future

Supporting Next G (6G)

cisco Live!
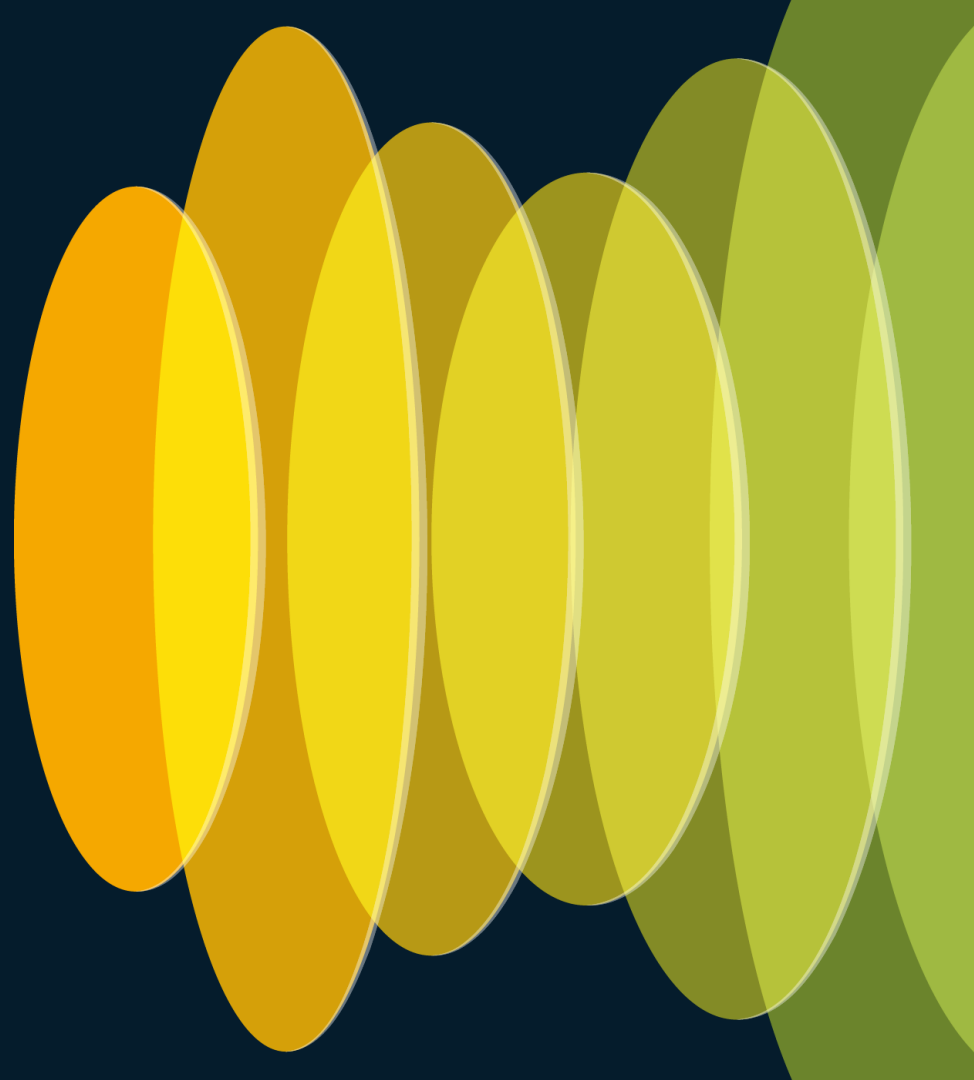
Cisco Quantum Random Number Generator (QRNG)

- 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
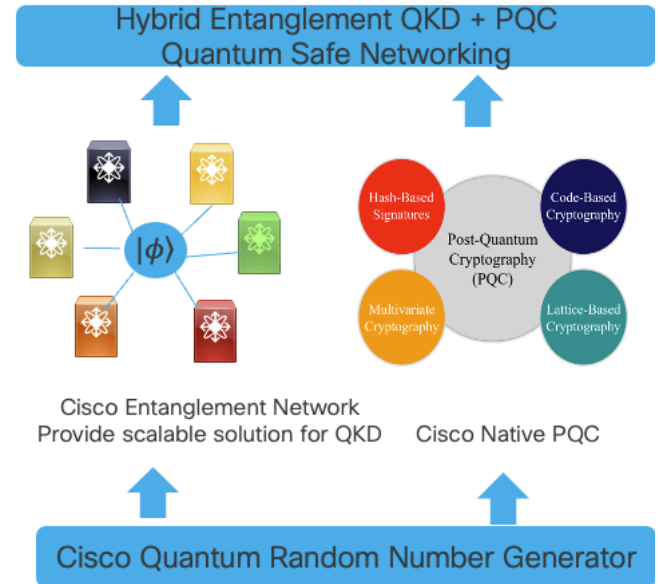 - Gambling and betting

Cisco Quantum Random Number Generator (QRNG)

- QRNG utilizing quantum uncertainty is able to generate true random number

- Quantum noise can be used as a source for random number generation

  - Vacuum signal is used as quantum noise source

  - Quantum noise is used to generate true random number
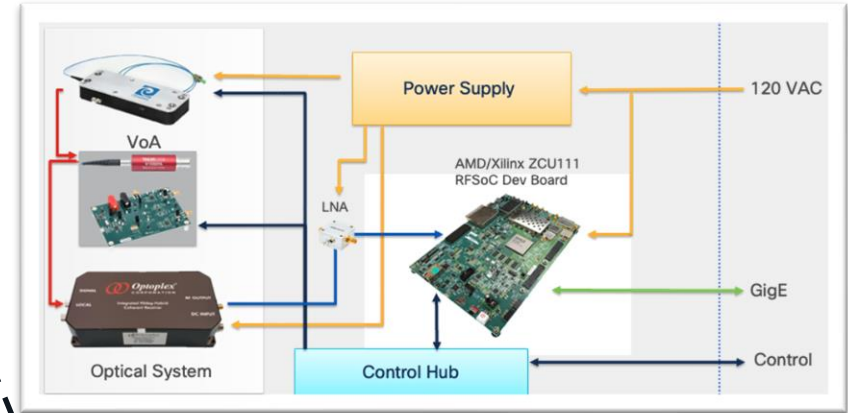
Quantum Network of the Future Supporting Quantum Safe Networking

- Future Network must be quantum safe
  - Quantum computers are able to break classical cryptography protocols
    - Any adversary can store copy of and encrypted data
    - Wait for a quantum computer to become available to decrypt
- Future Networks will require new quantum computing proof security
  - Two possible solutions
    - Quantum cryptography
    - Post quantum cryptography

Hybrid Entanglement QKD + PQC
Quantum Safe Networking

$|\phi\rangle$

Hash-Based Signatures
Code-Based Cryptography
Post-Quantum Cryptography (PQC)
Multivariate Cryptography
Lattice-Based Cryptography

Cisco Entanglement Network
Provide scalable solution for QKD

Cisco Native PQC

Cisco Quantum Random Number Generator

Quantum Network of the Future
# Supporting Quantum Computing as A Service

- Quantum computing for network control and management
  - Telecom network optimization
    - Complex and heterogeneous across RF and optical
    - Time variant and stochastic process and interaction between user, spectrum , device, application
    - These problem can be mapped to quantum uncertainty problems to be solved by quantum machine learning techniques.

- Providing quantum computing as a service
  - Quantum cloud computing
  - Quantum data center (QDC)
  - Quantum edge computing

Quantum Network of the Future
Dynamic Quantum Entanglement Network

- Capability for routing and switching of entangled qubits

- Support for establishing entanglement between any two nodes in the network.

- Support for coexistence of classical and quantum channels over the same network.

- Offer quantum network resources such as entangled photons and Bell state measurement devices (BSM) as a service to network users.
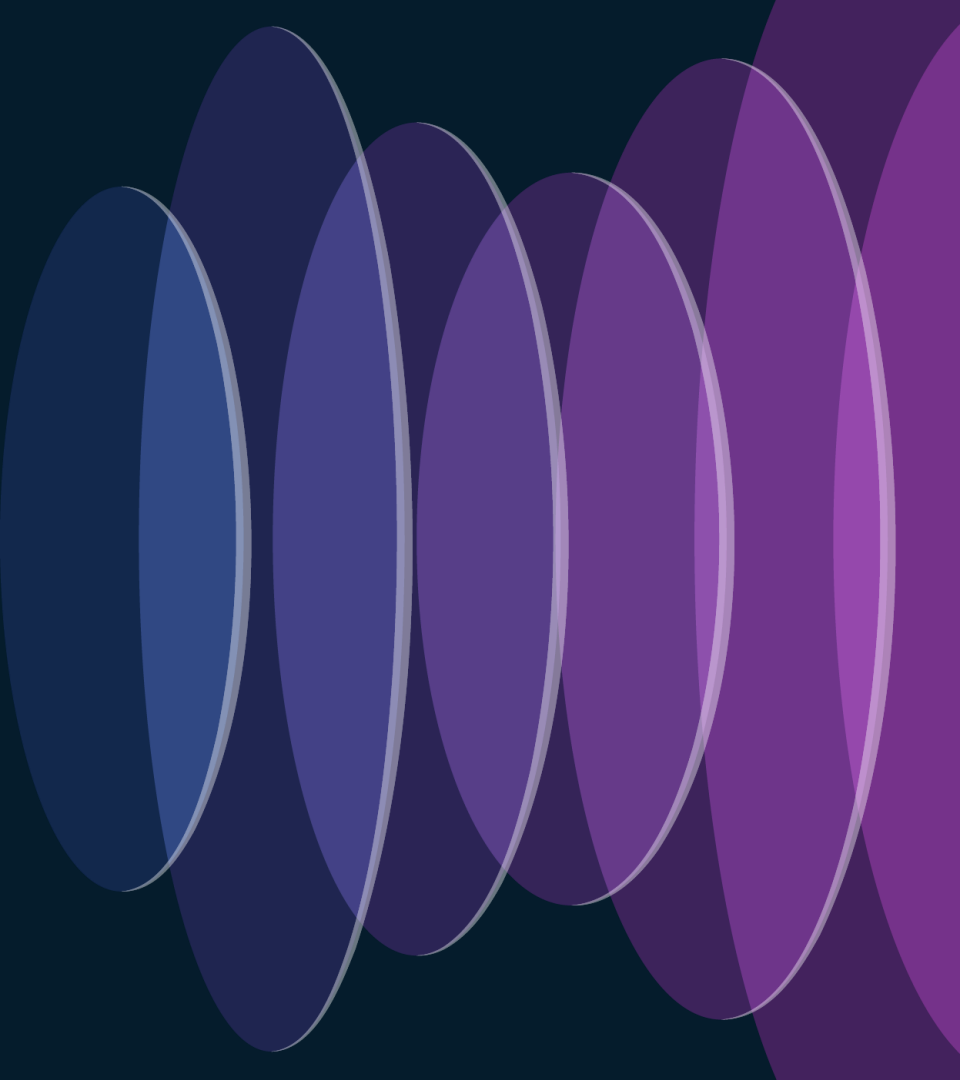
- Support for quantum repeaters
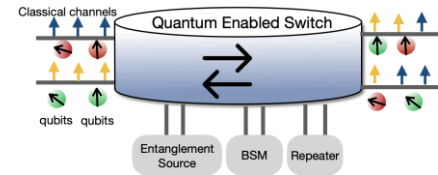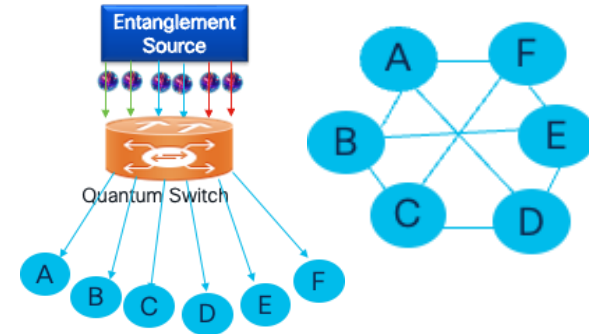
Co-Existence of Quantum and Classical channels

Cisco Vision for Future Quantum Networks
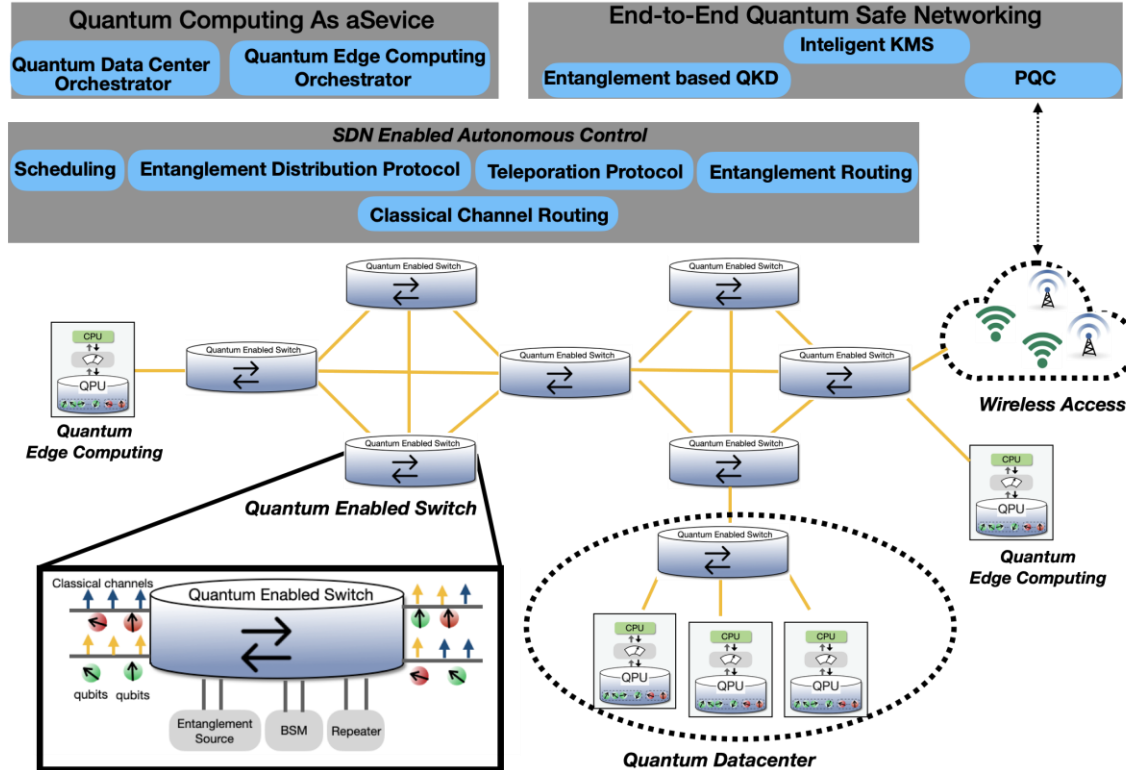
Quantum Network Digital Twin for Quantum Network Planning, Modeling & Up Skilling and Training
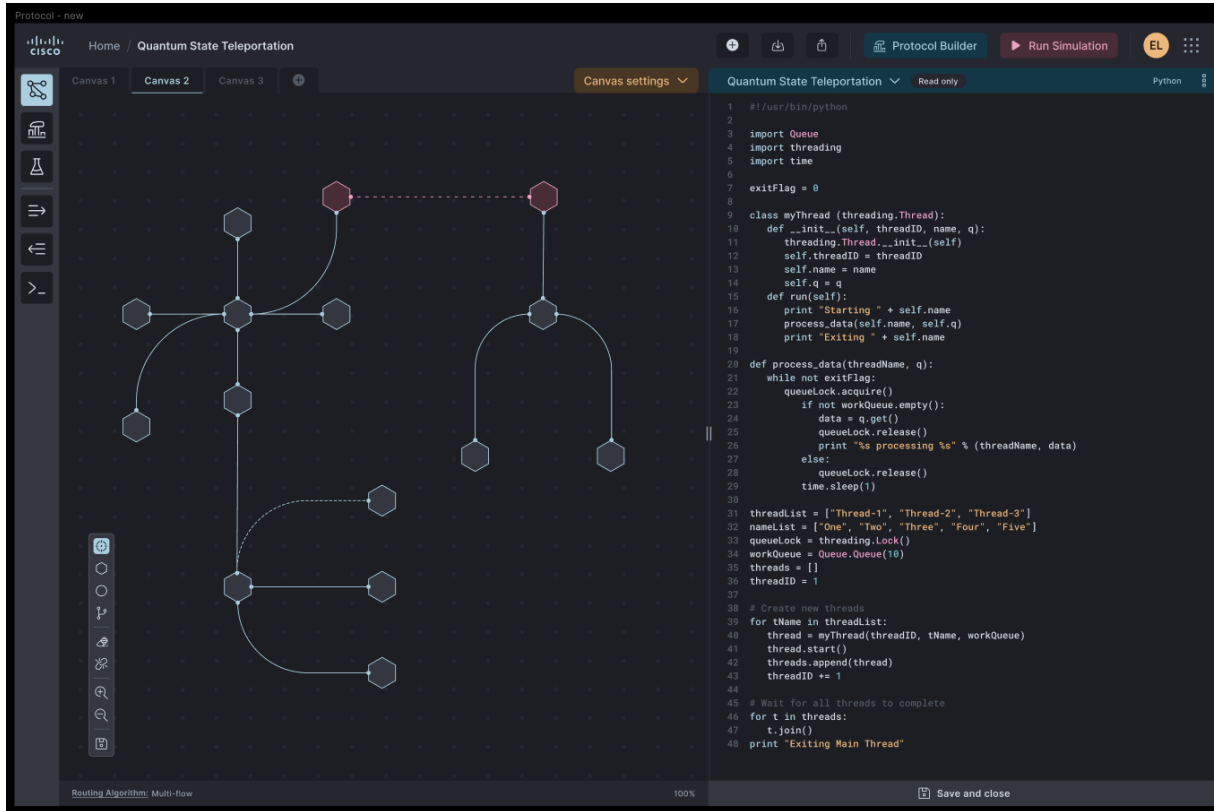
What is Cisco's Quantum Network Digital Twin QNetLab

- 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 Quantum Network Digital Twin (Cloud based)

Quantum Network Simulator

Quantum Network Emulator

Quantum Network Live Test-bed

QNetLab Quantum Network Development Kit

Rela time Test-bed Connectivity
Connecting it to Test-bed and Emulation Environment
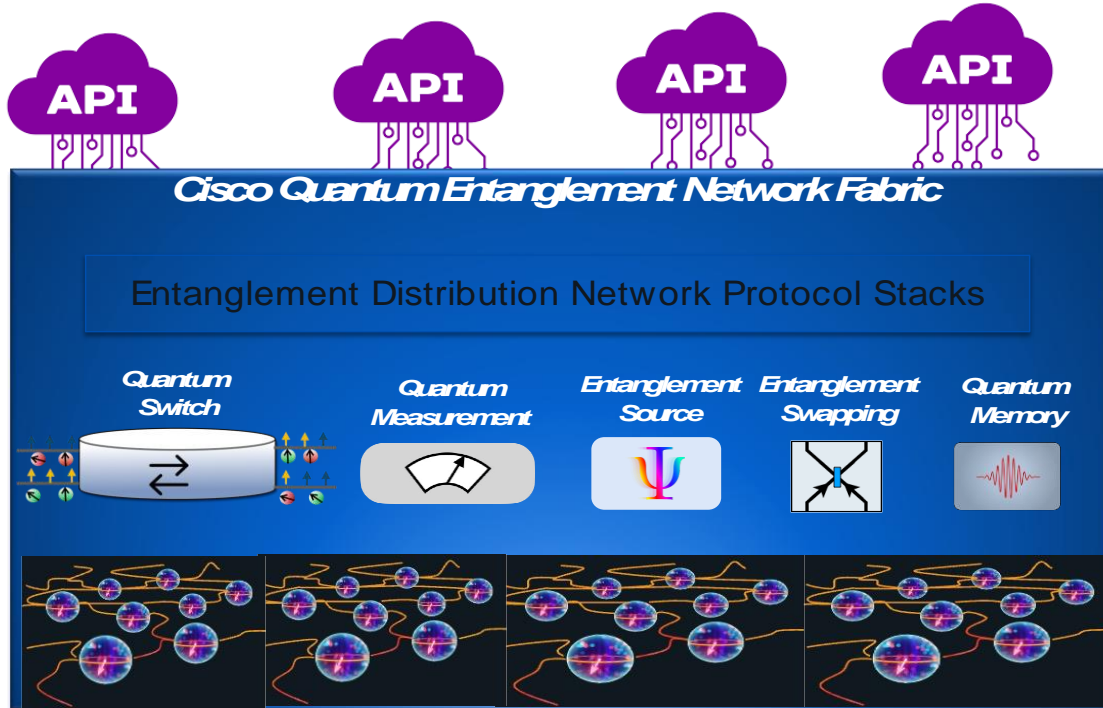
We are Building a
Practical and Useful Quantum Network

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Earn 100 points per survey completed and compete on the Cisco Live Challenge leaderboard.

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Thank you

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