Cisco’s Quantum Network

How Cisco is Building Tomorrow's Infrastructure, Today

Reza Nejabati
Head of Quantum Research and Quantum Labs

BRKETI-2009

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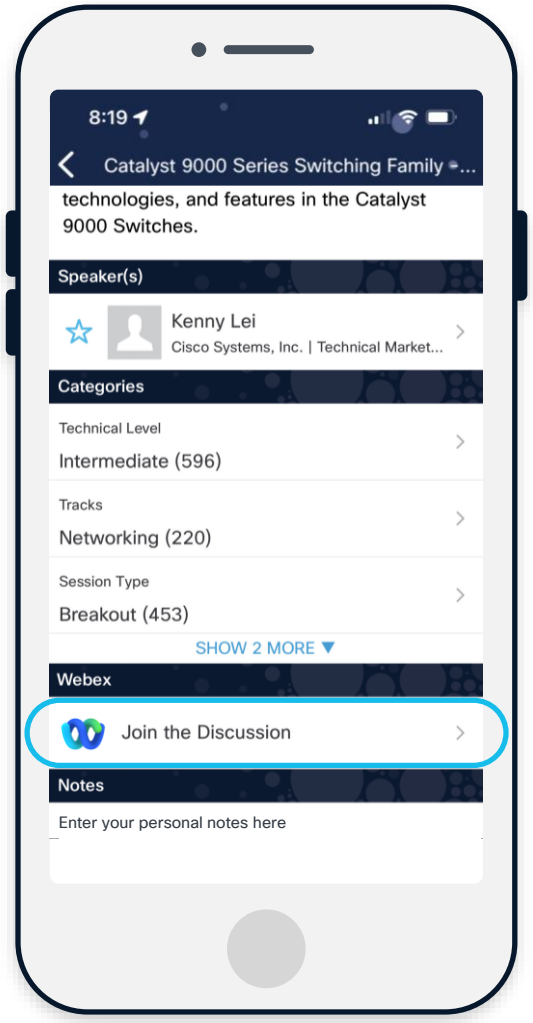


Agenda

01 Harnessing Power of Quantum

02 Cisco Vision & Road Map

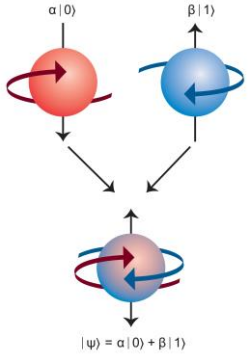
03 Cisco Quantum Network Technology

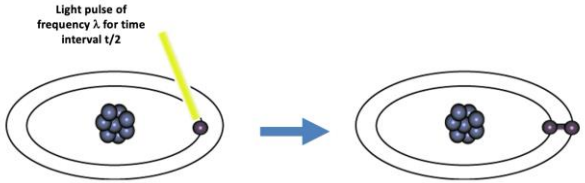
04 Demo

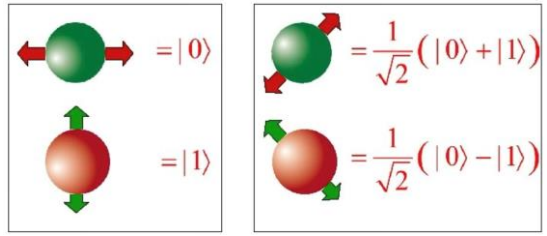
Harnessing Power of Quantum

What is Quantum Bit (qubit)

- Classical bit : 1 or 0
- Quantum bit (qubit): $\alpha\,|1\rangle + \beta\,|0\rangle$ | , α | $+^2|\beta|^2=1$
- Generating qubit:
  - Nuclear spin
  - Positive /Negative
  - Electron state
  - Ground/ Excited
  - Polarization of photon
  - Vertical / Horizontal/ Diagonal

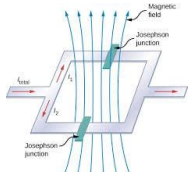


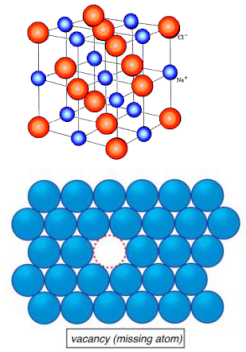


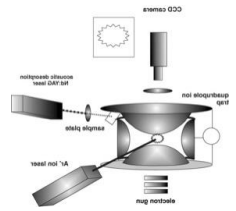


Realizing a Quantum Bit (qubit)

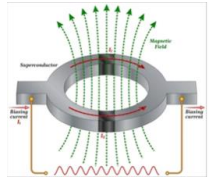
- Matter qubits can reside in supercunducting ring, atoms (ion), crystal defects (NV-center), atomic ensembles



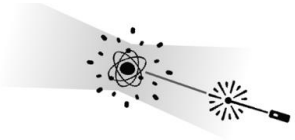




Charged Atom



Superconducting



Neutral Atom

Millikelvin (mK)+ Vacuum

- Flying qubits are transported on photon (visible or telecom wavelength)

Quantum Computing

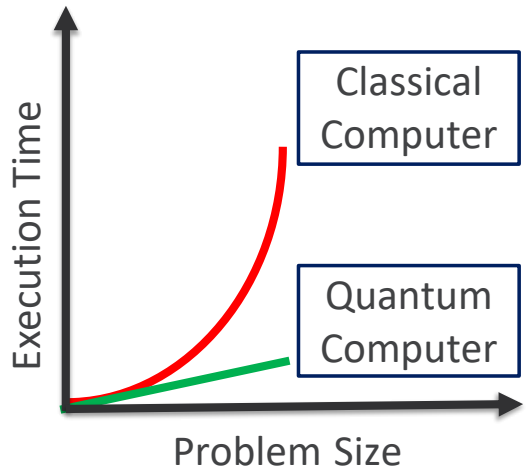
- Quantum Computing Supremacy:
  - 2 qubits: superposition of 4 possible basis states
  - 3 qubits: superposition of 8 possible basis states
  - n qubits: superposition of 2^n possible basis states

Superposition (of qubits)

classical: 0100110101

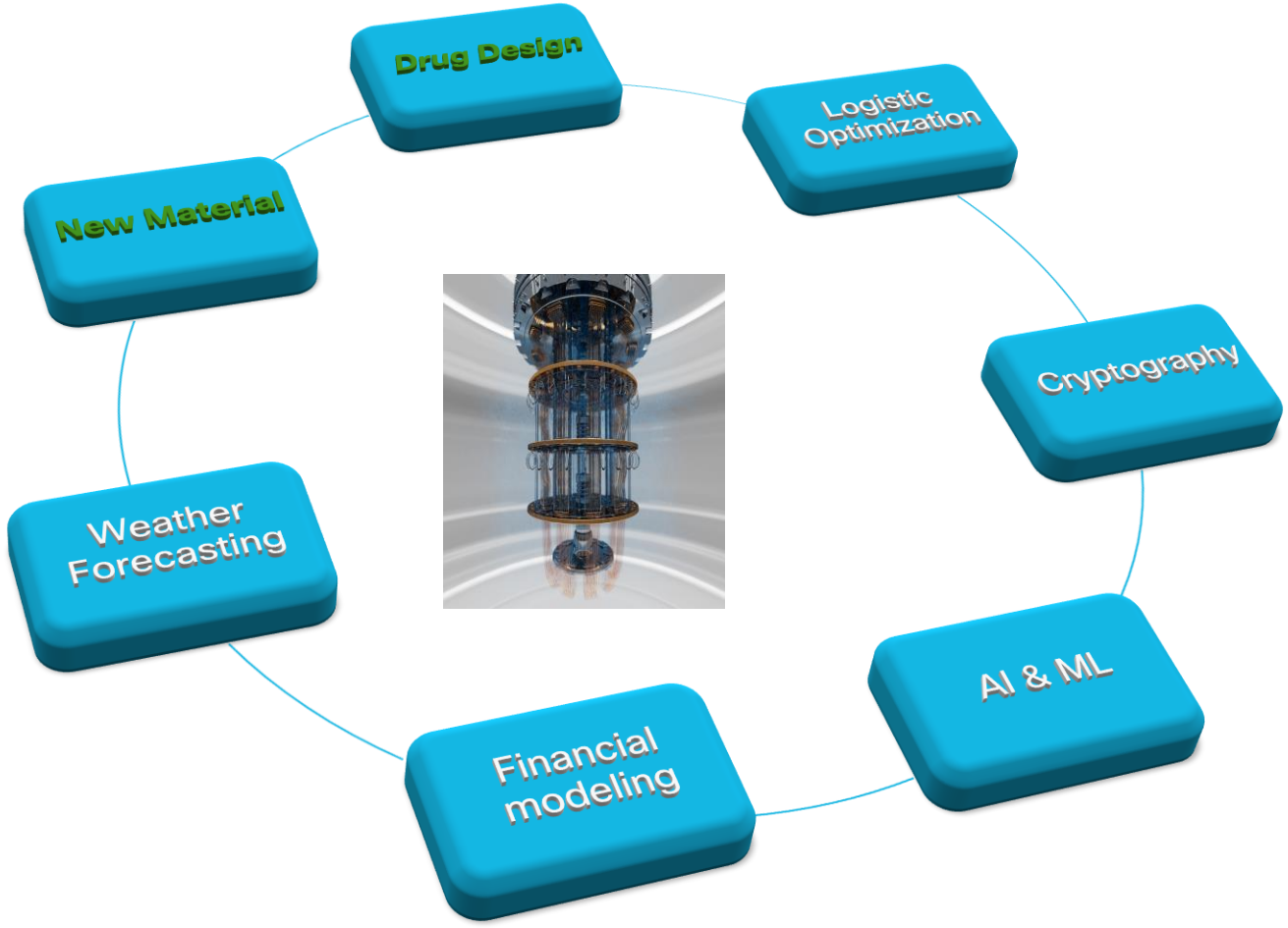
quantum:

$$p_0 0000000000$$
$$+p_1 0000000001$$
$$+p_2 0000000010$$
$$\cdots$$
$$+p_{2^N} 1111111111$$



Quantum Computing Applications

- Quantum Computers are not universal
  - They are good for specific applications

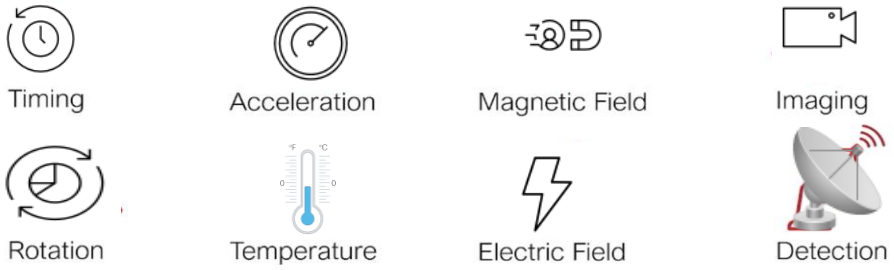


Quantum Sensing

- 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

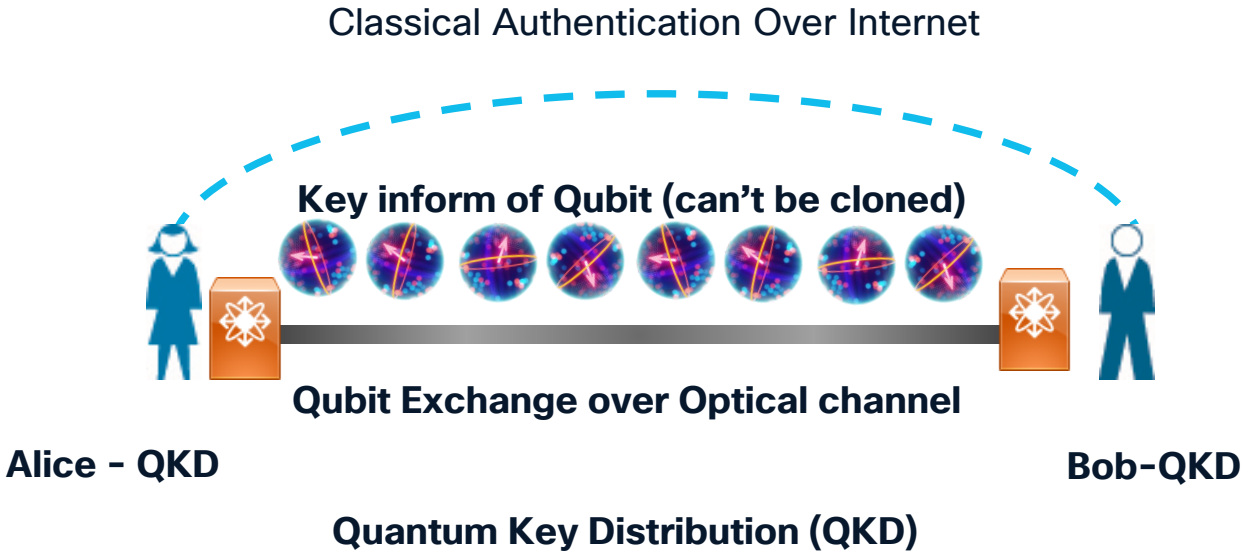
- They have optimized precision and beat current limits in sensor technology.

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



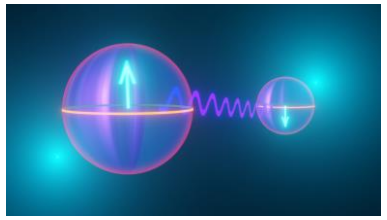
Quantum Security

- 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



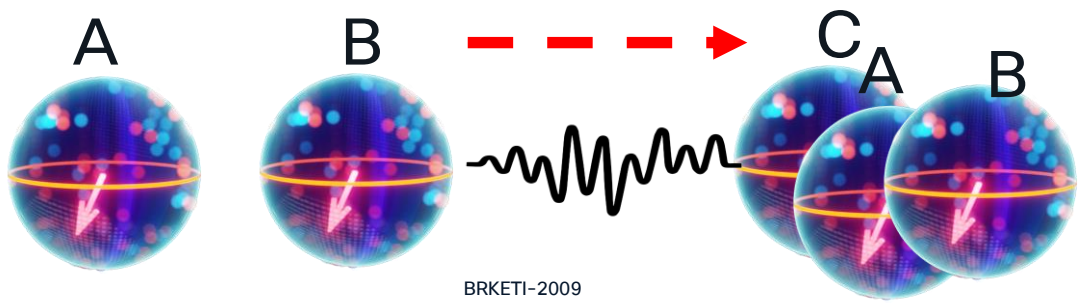
Quantum entanglement

- 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

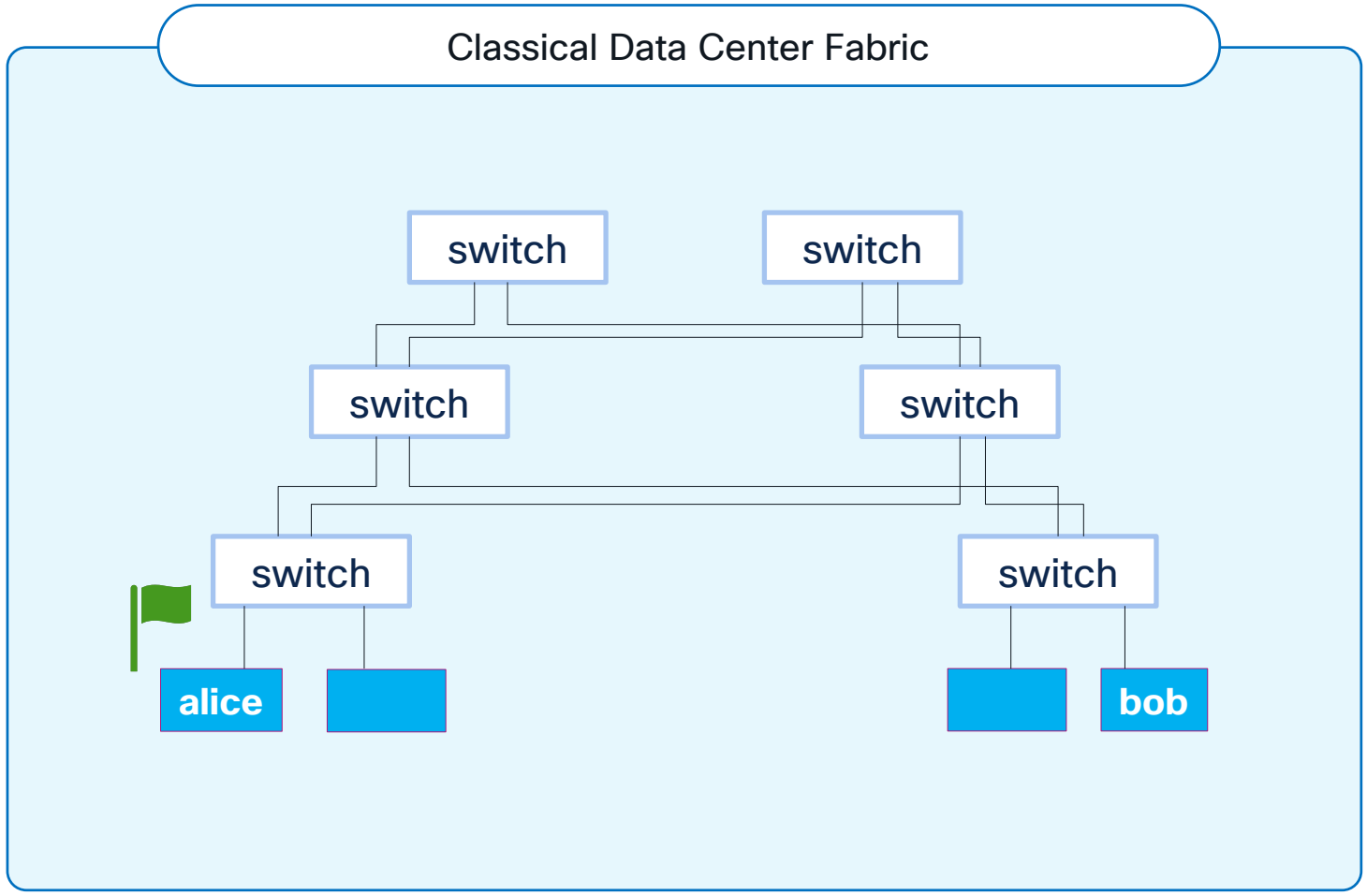


Quantum Teleportation

- **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**



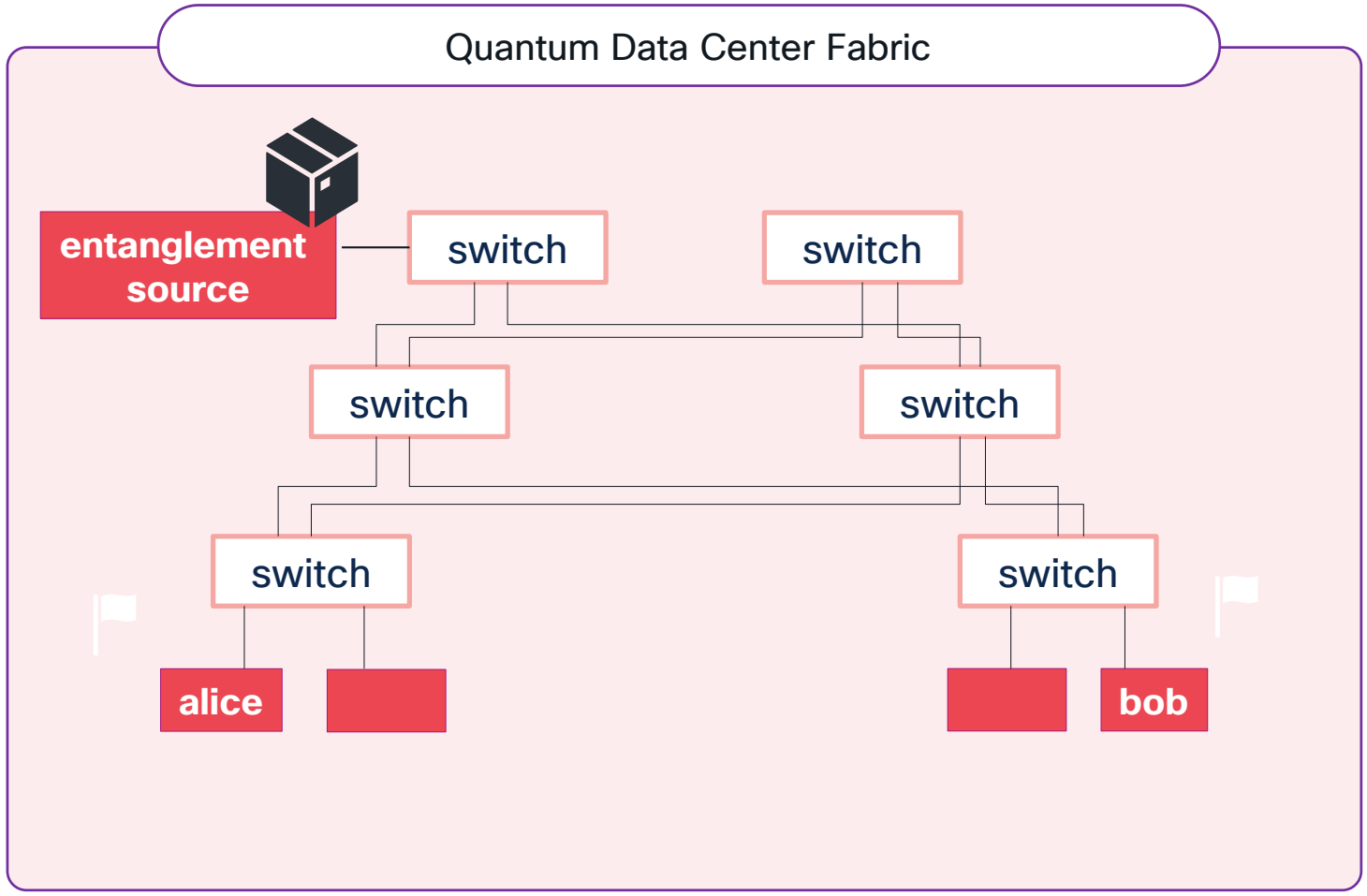
Classical Data Center Networking



Send information between Alice & Bob

- Alice creates Bit of information
- Sends bit hop-by-hop through network
- Bob receives Bit of information
- Network is used to send information

Classical Data Center Networking



Send carrier of info to Alice & Bob

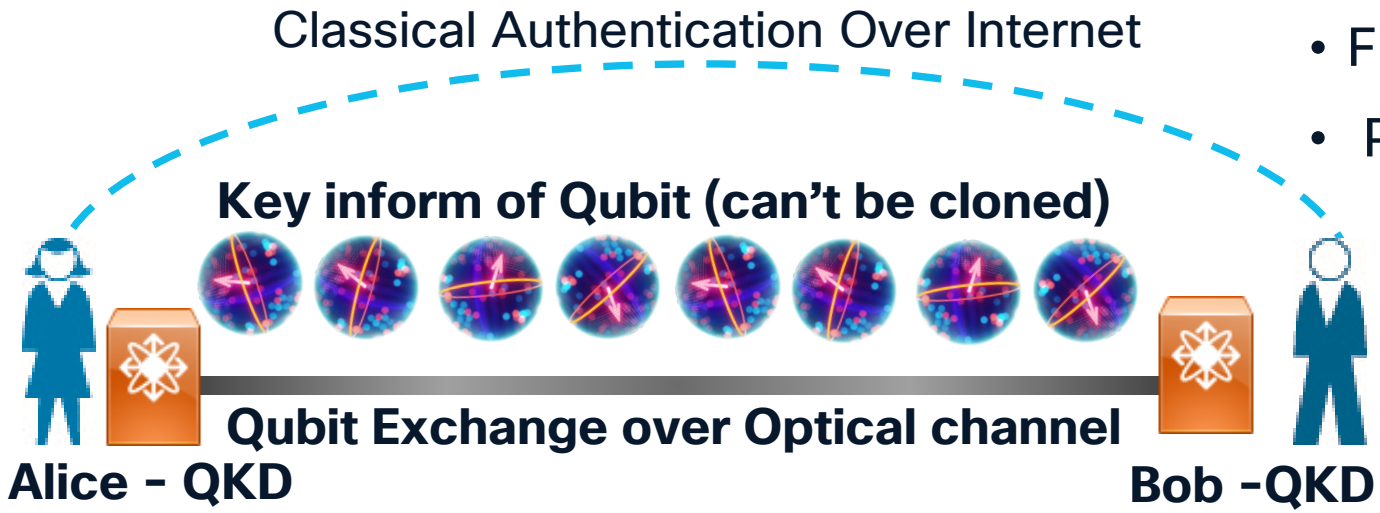
- Two particles (photons) at distance mirror each other without any physical physical connection

Send carrier of info to Alice & Bob

- Network is for out-of-band / control traffic
- Carrier for quantum property sent to Alice and Bob through the network
- This is using the **entanglement** property of photons
- As carrier decays, it is refreshed through the network

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

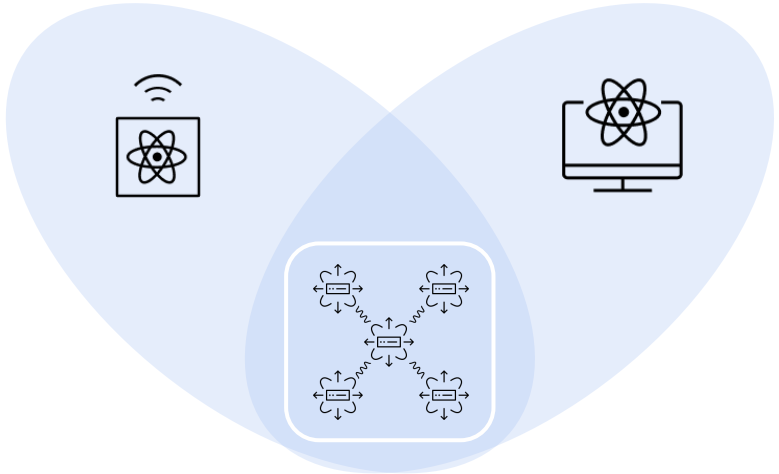
- Point-to-Point quantum connectivity
  - **Static, no dynamicity, no switching, no routing**
- Specific to security use cases
  - For quantum key distribution QKD
  - Not a full security solution : Securing only optical Link, not end nodes or wireless
- Needs dedicated HW, dictated fiber, dedicated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

Cisco Vision & Road Map

Quantum Technology Ecosystem & Cisco Focus

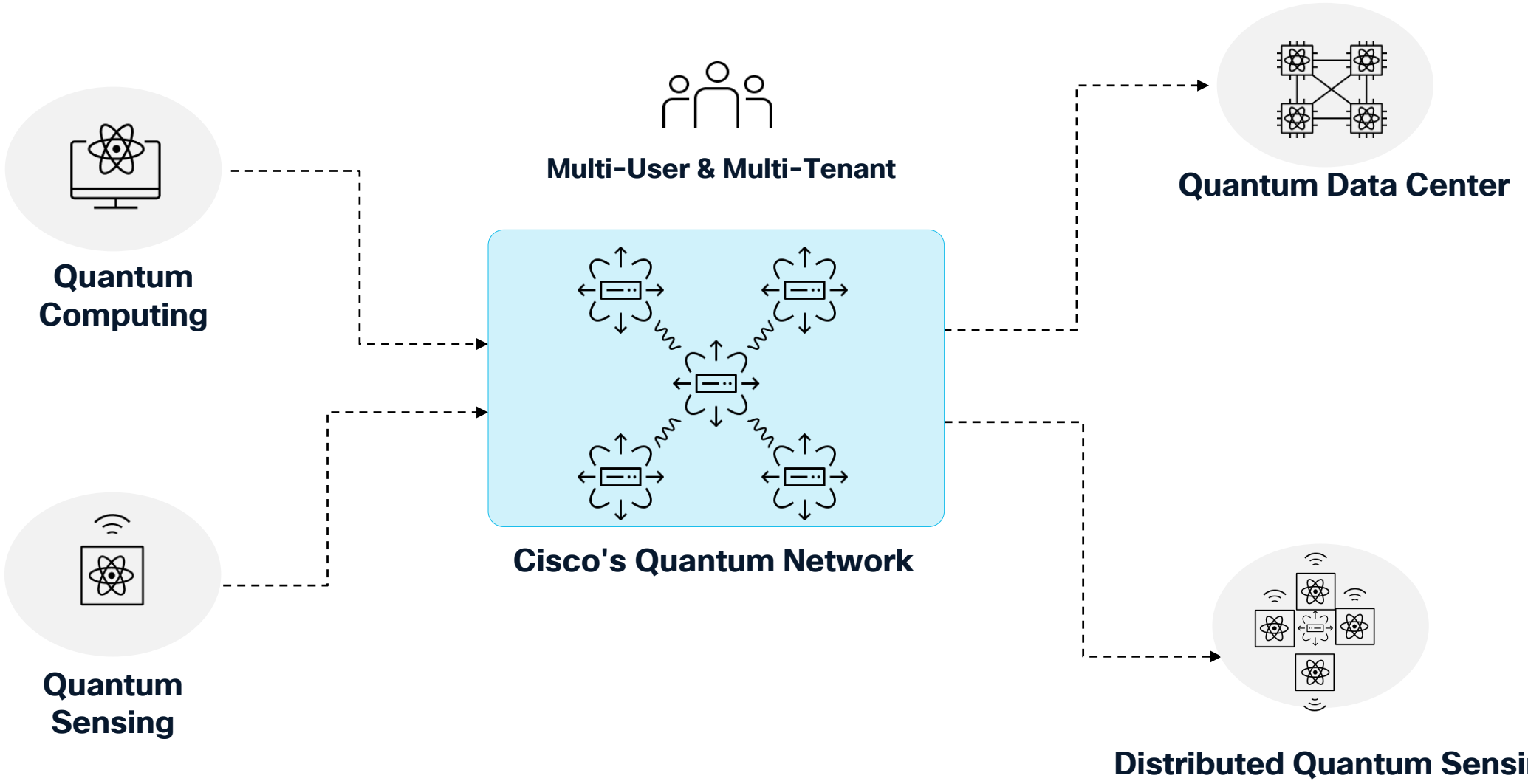
Quantum Sensing
[1000+ more sensitivity]

Quantum Computing
[Exponentially more powerful]

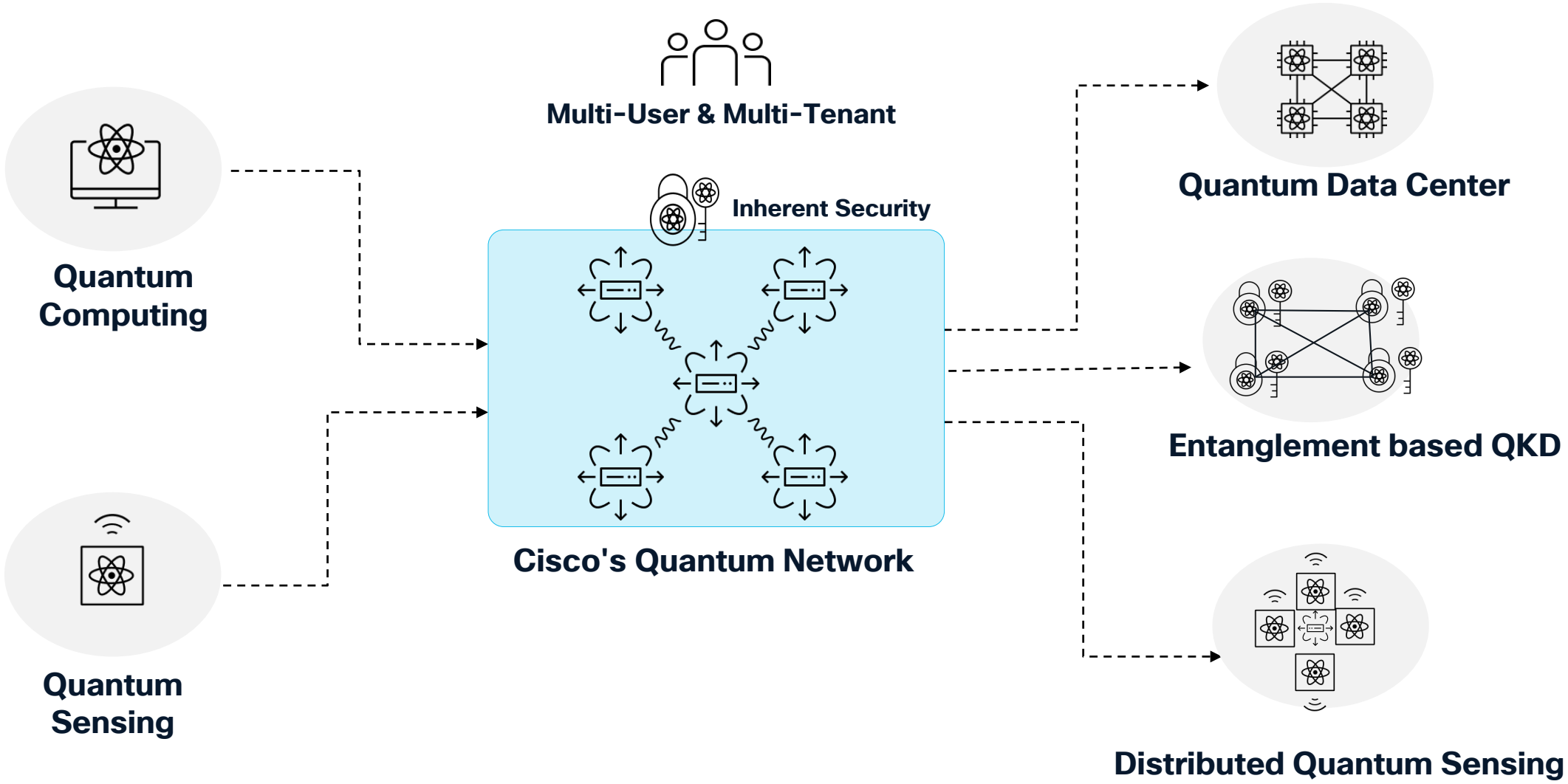


Quantum Networking
Cisco's Focus
[Connect quantum computing and sensing devices to scale out]

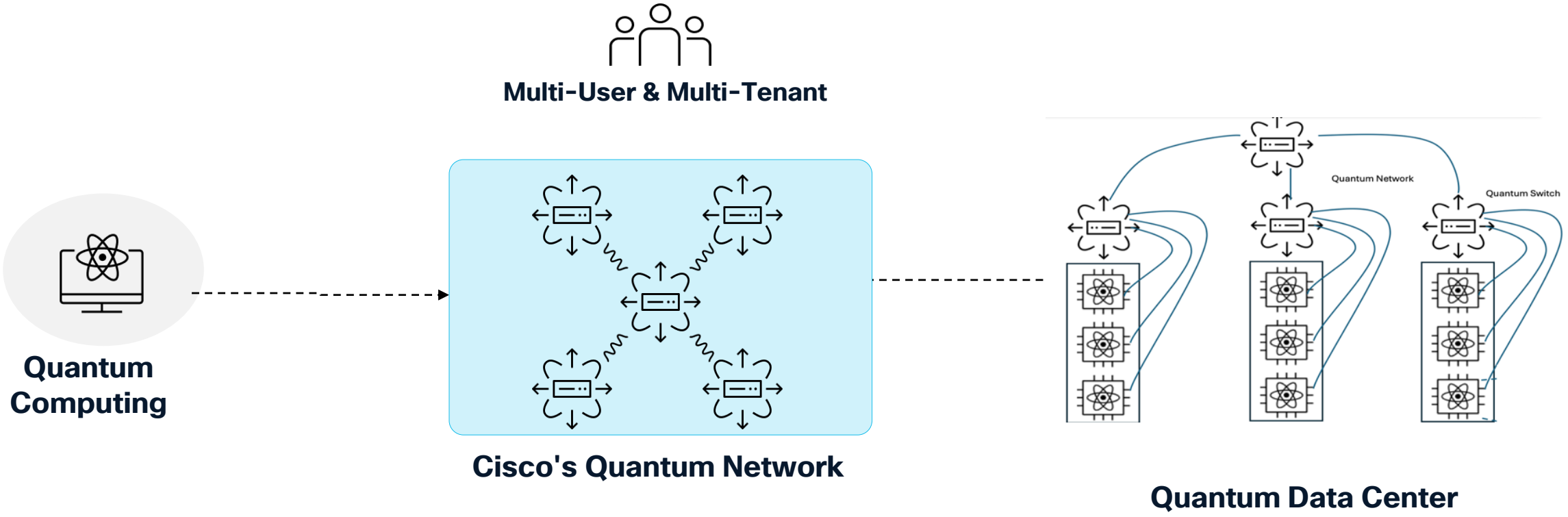
Cisco Quantum Network Vision



Cisco Quantum Network Vision



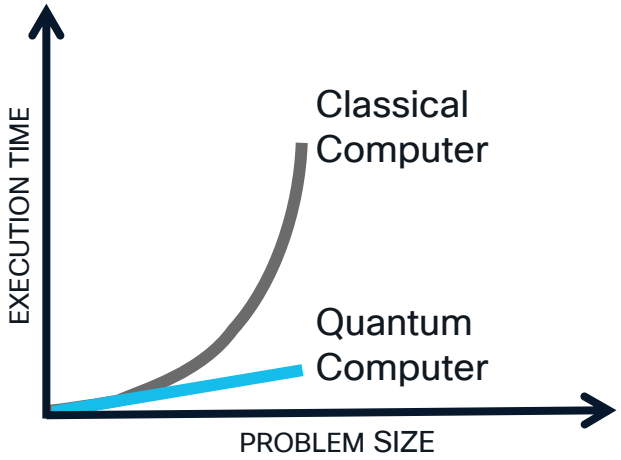
Cisco’s Final Goal in Quantum Computing



Cisco's Final Goal in Quantum Computing

Use Cases Today:

- Financial forecasting
- Drug discovery
- Logistics optimization
- Cryptography
- New Material
- Weather forecasting



At-scale (fault tolerant) quantum computing will require 1M+ physical qubits

We focus on

- distributed quantum computing
- quantum networking

- What is a Quantum Data Center
  - Warehouse scale distributed quantum computing
    - Hyper scalers' approach
    - Create a scalable quantum computing by networking large number of small processor
- Why a quantum data center
  - Controlled environment
  - Short distance
  - Practical to create an entanglement distribution network at scale for quantum computing interconnect
- Cisco's focus on key innovations to build a useful and practical quantum network of quantum computers interconnect in data center

Cisco's Quantum Network Use Cases

Quantum for the Quantum World

Ultra-precise Sensing

- Distributed quantum sensing to improve the sensing precision by 10-1000x
- **App:** biological imaging
- **Sector:** Medical, defense, metrology

Quantum Data Centers

- Distributed quantum computing via quantum network interconnects
- **App:** Molecular simulations, AI/ML, Optimization
- **Sector:** pharma, hyper-scalers, logistics

Quantum for the Classical World

Decision Coordination

- Instantaneous decision coordination between remote parties with quantum telepathy
- **App:** high-frequency trading (HFT)
- **Sector:** fintech

Secure Position Verification

- Secure authentication of geographic location of a party using quantum verifiers
- **App:** financial transactions, tracking soldiers/spies
- **Sector:** fintech, defense, security

Ultra-precise Time Synchronization

- Pico second clock sync between remote parties using quantum teleportation
- **App:** consensus protocols, HFT, robotic
- **Sector:** fintech, defense, manufacturing

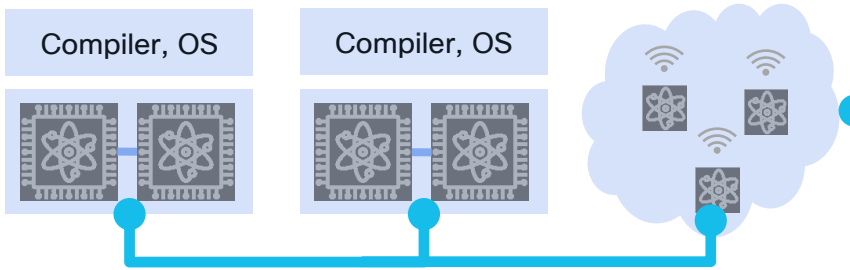
Eavesdropper-Proof Security

- Using single-photon quantum signals to detect eavesdroppers on optical fibers
- **App:** Quantum Key Distribution (QKD)
- **Sector:** fintech, telecom, government

Cisco's Focus in Quantum Technology

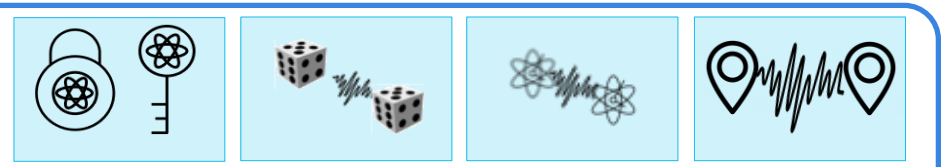
Quantum Applications

Quantum Network for Quantum Computing & Sensing

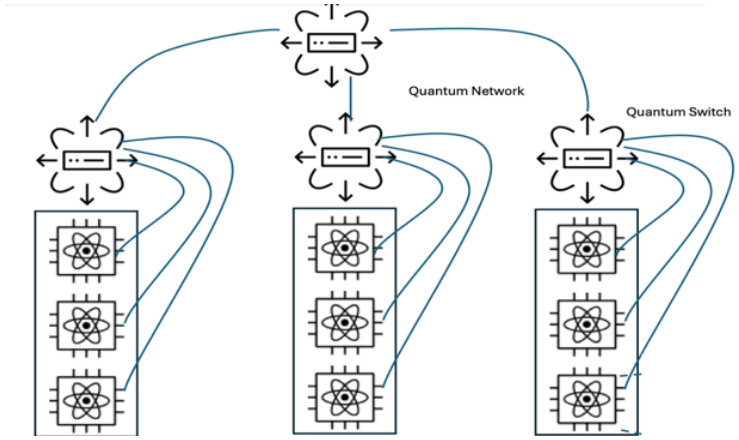


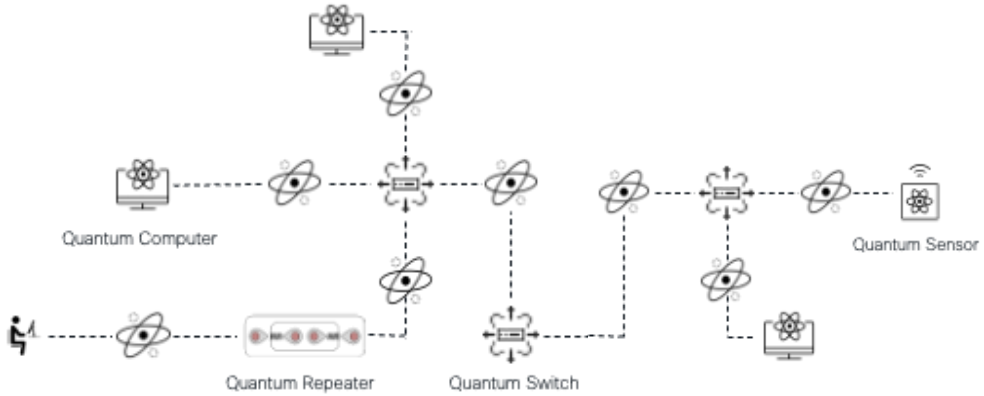
Quantum Internet

Quantum Network for Classical Application

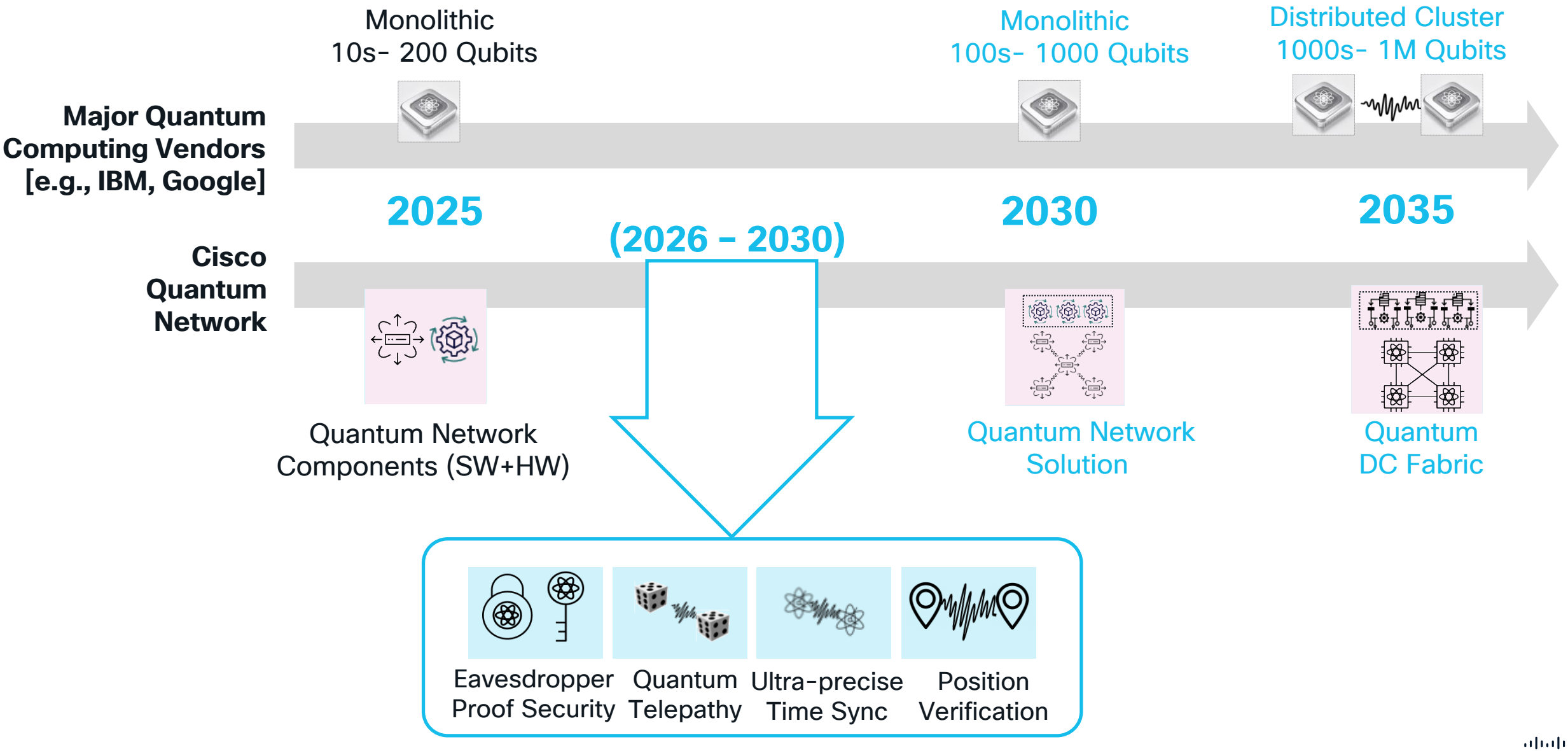


Eavesdropper Proof Security | Quantum Telepathy | Ultra-precise Time Sync | Position Verification

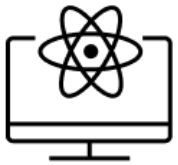




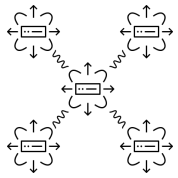
Road Map



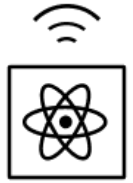
The total internal market size



Quantum Computing



Quantum Networking



Quantum Sensing

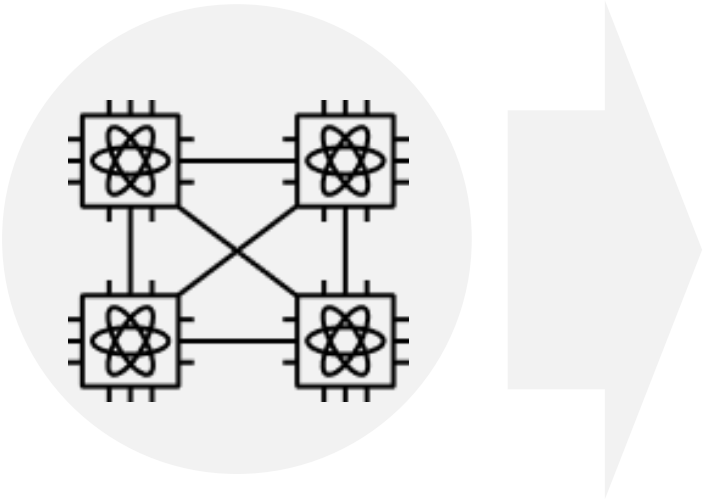
	Conservative	Optimistic	Conservative	Optimistic	Conservative	Optimistic
2035	$28B	$72B	**$11B**	**$15B**	$0.5B	$2.7B
2040	$40B	$131B	**$24B**	**$36B**	$1B	$6B

Source McKinsey

Cisco Quantum Network Technology

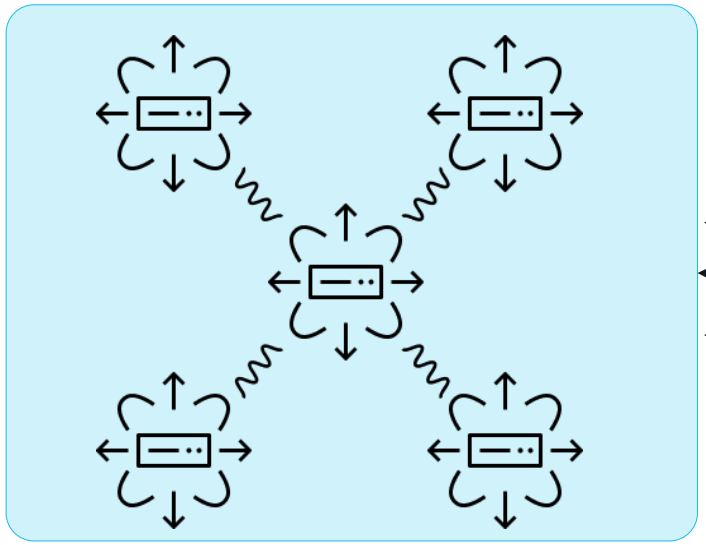
Cisco Quantum Network Design for the Data Center

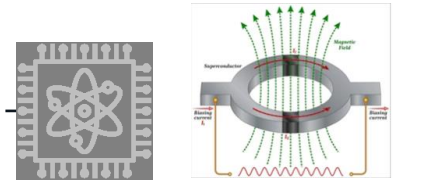
Quantum Data Center



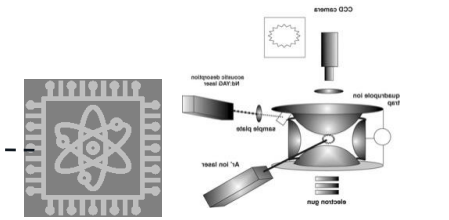
Cisco's Quantum Network

- High Fidelity Entanglement Distribution Network
- Quantum Computing Technology Agnostic
- Multi-User & Multi-Tenant, Workload-aware

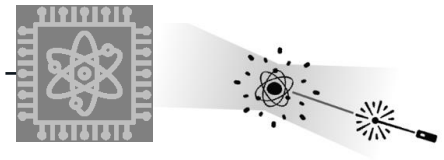




Superconducting



Charged Atom



Neutral Atom

1 Cisco's QN-Fabric (Hardware)

2 Cisco's QN-Orchestra (Software)

Cisco’s Quantum Network Stack

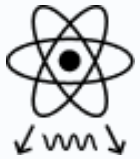
Quantum Network Control Plane (QN-Orchestra)

Distributed Quantum Computing **Compiler** (Network-Aware, Multi-Tenant)

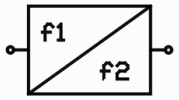
Network **Protocols** and Software for **Entanglement Distribution**

Quantum Entanglement Network Fabric (QN–Fabric)

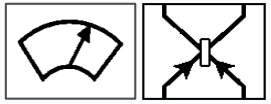
Quantum Entanglement Source



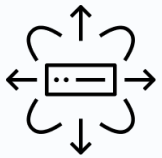
Quantum NIC



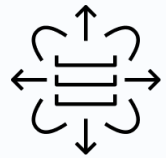
Quantum Measurement



Quantum Switch



Quantum Memory



Cisco’s Quantum Network Stack

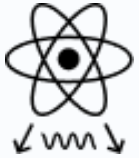
Quantum Network Control Plane (QN-Orchestra)

4 Distributed Quantum Computing **Compiler** (Network-Aware, Multi-Tenant)

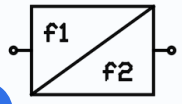
Network **Protocols** and Software for **Entanglement Distribution**

Quantum Entanglement Network Fabric (QN–Fabric)

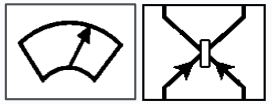
1 Quantum Entanglement Source



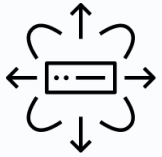
2 Quantum NIC



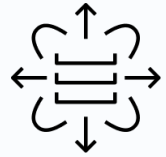
Quantum Measurement



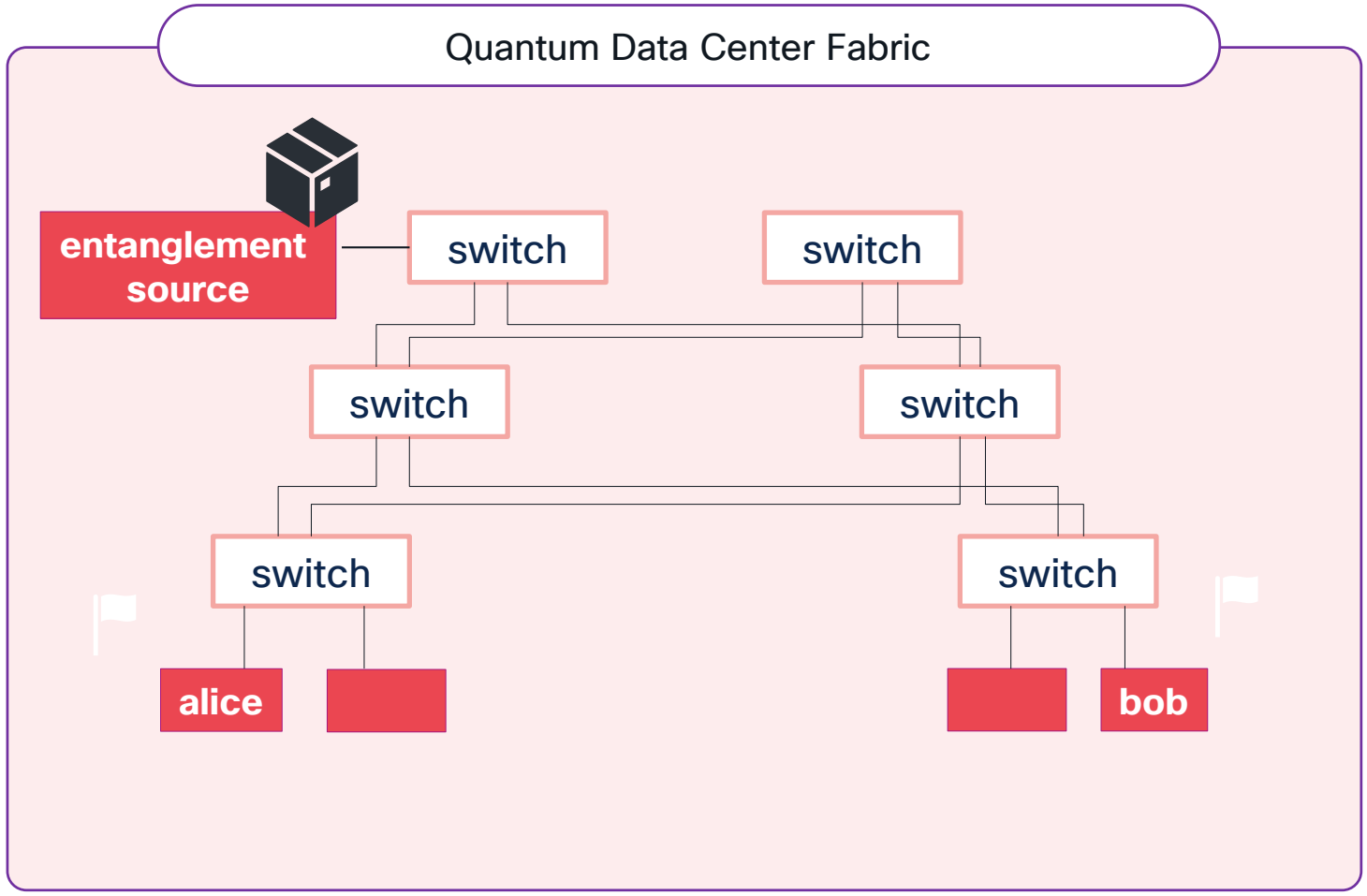
3 Quantum Switch



Quantum Memory



Classical Data Center Networking



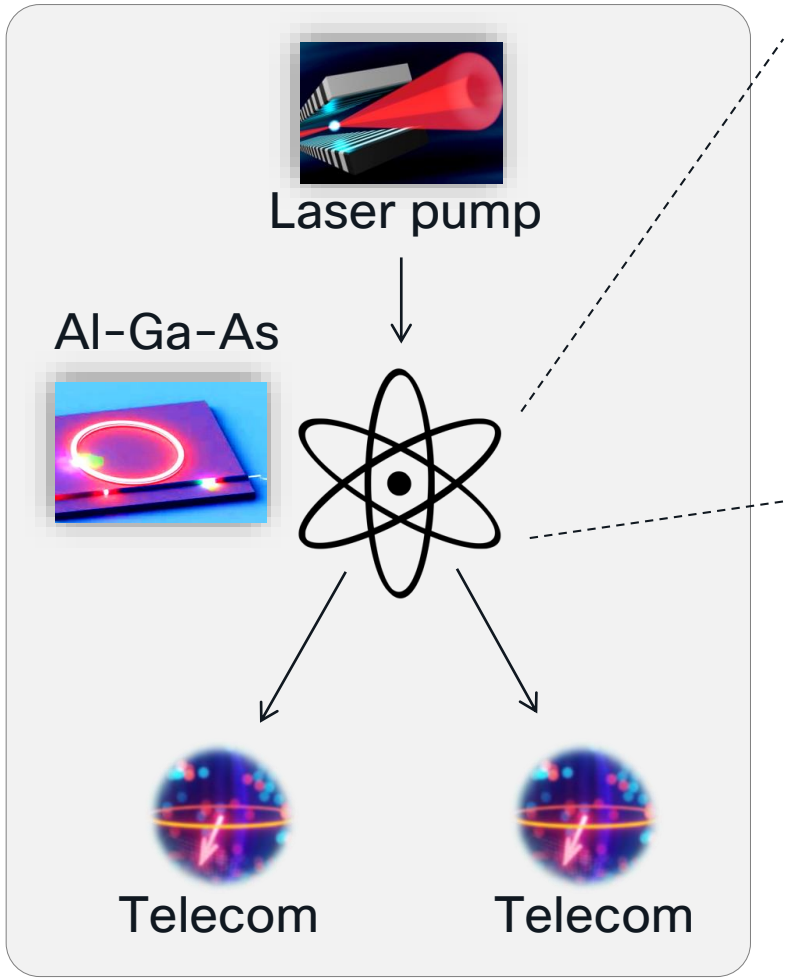
Send carrier of info to Alice & Bob

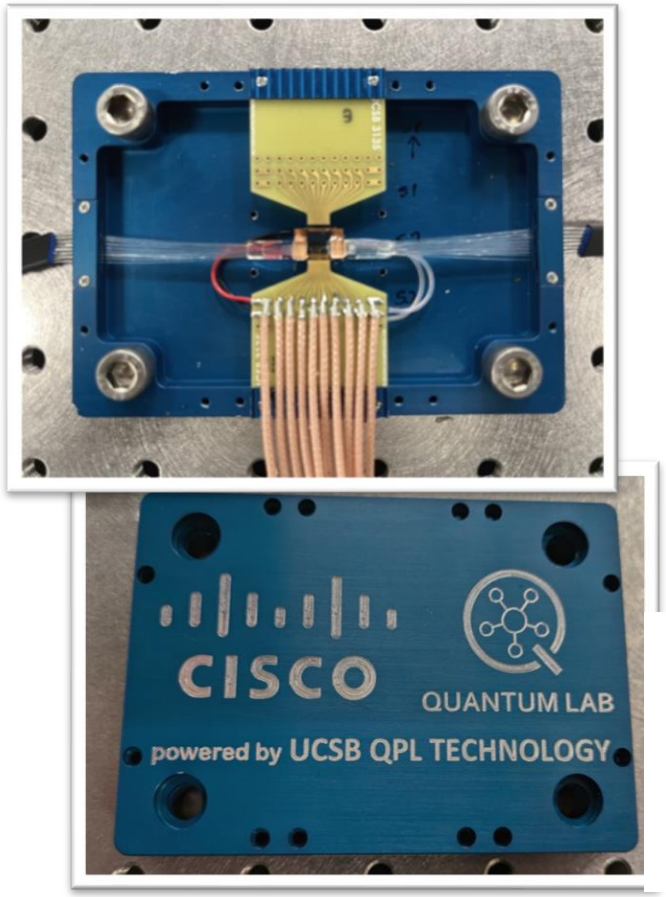
- Two particles (photons) at distance mirror each other without any physical physical connection

Send carrier of info to Alice & Bob

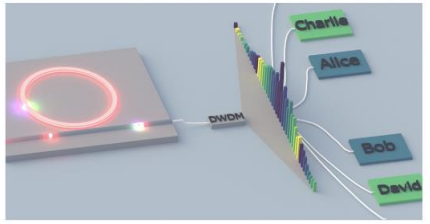
- Network is for out-of-band / control traffic
- Carrier for quantum property sent to Alice and Bob through the network
- This is using the **entanglement** property of photons
- As carrier decays, it is refreshed through the network

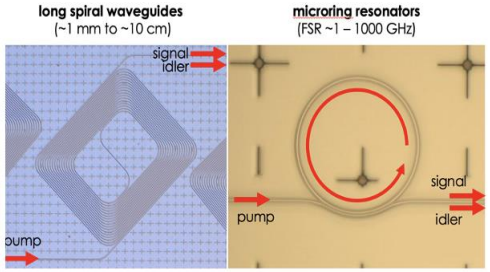
1 Quantum Entanglement Sources



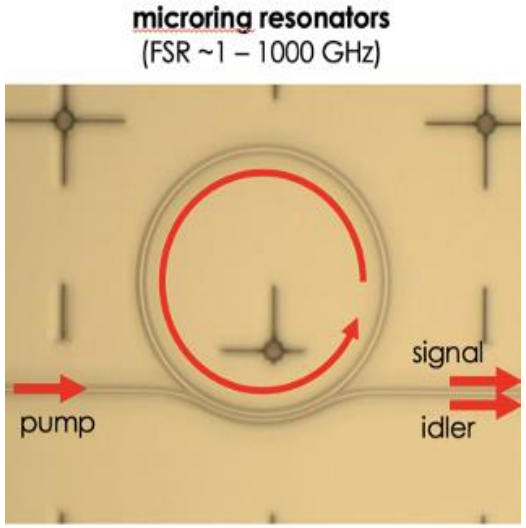


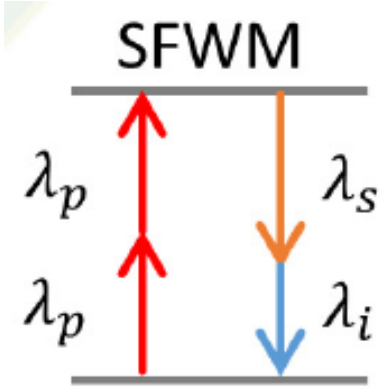
- **High rate:** >1M pair/s per-channel, 200M pair/s inchip
- **High fidelity:** > 99%
- **Low power:** < 1mW
- **Small form factor:** 100µm on photonic integrated chip

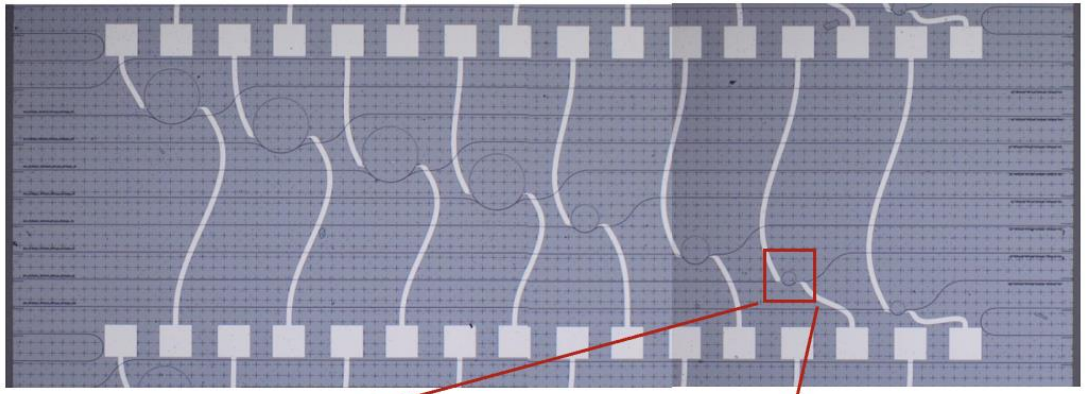


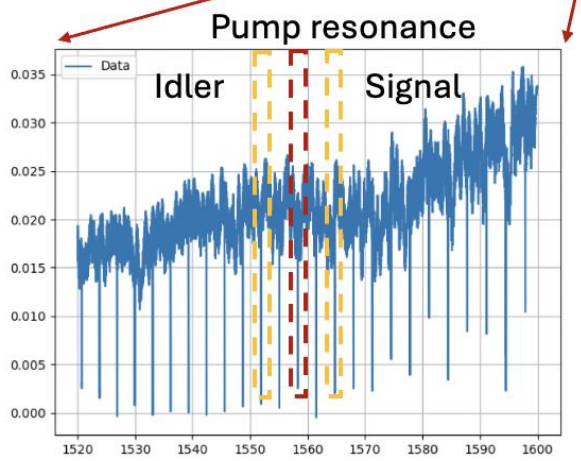


1 Quantum Entanglement Sources









Cisco’s Quantum Network Stack

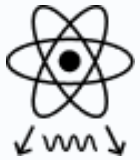
Quantum Network Control Plane (QN-Orchestra)

Distributed Quantum Computing **Compiler** (Network-Aware, Multi-Tenant)

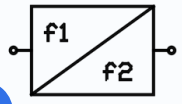
Network **Protocols** and Software for **Entanglement Distribution**

Quantum Entanglement Network Fabric (QN–Fabric)

Quantum Entanglement Source

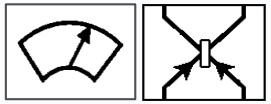


Quantum NIC

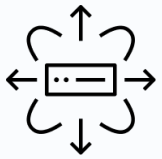


2

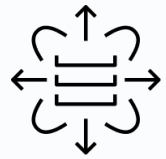
Quantum Measurement



Quantum Switch

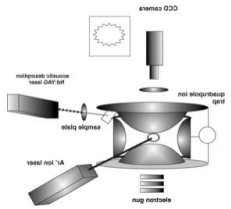


Quantum Memory

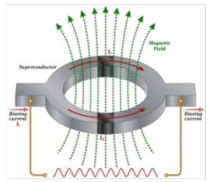


Realizing a Quantum Bit (qubit)

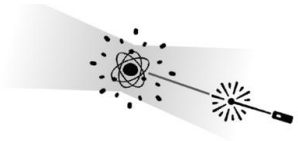
- Matter qubits can reside in supercunducting ring, atoms (ion), crystal defects (NV-center), atomic ensembles



Charged Atom



Superconducting

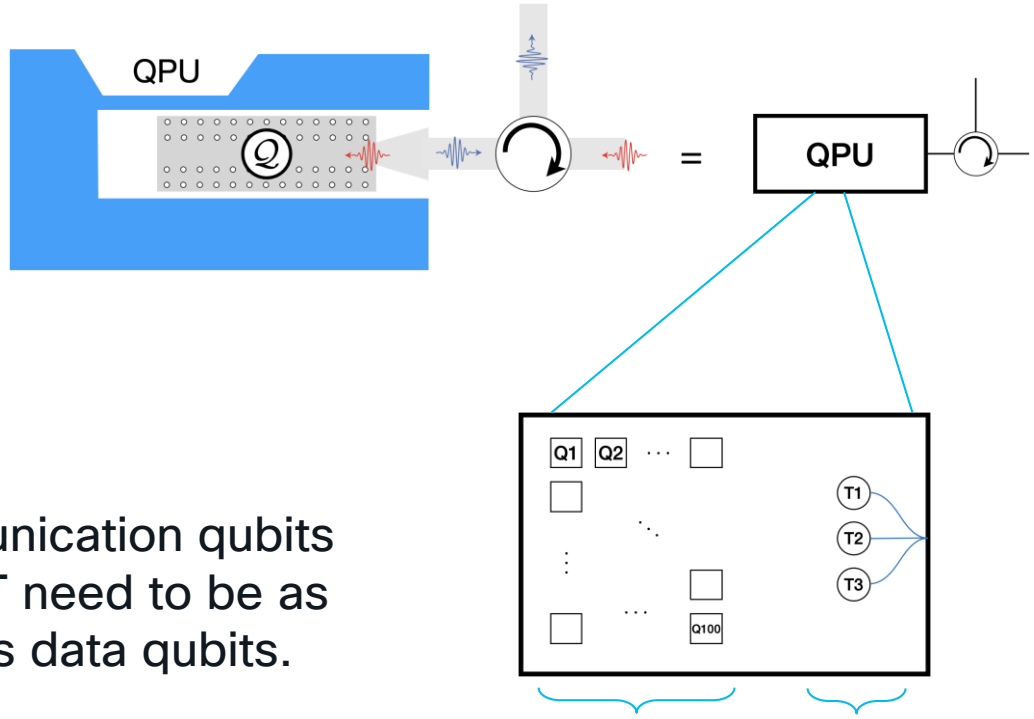


Neutral Atom

Frequency Mismatch

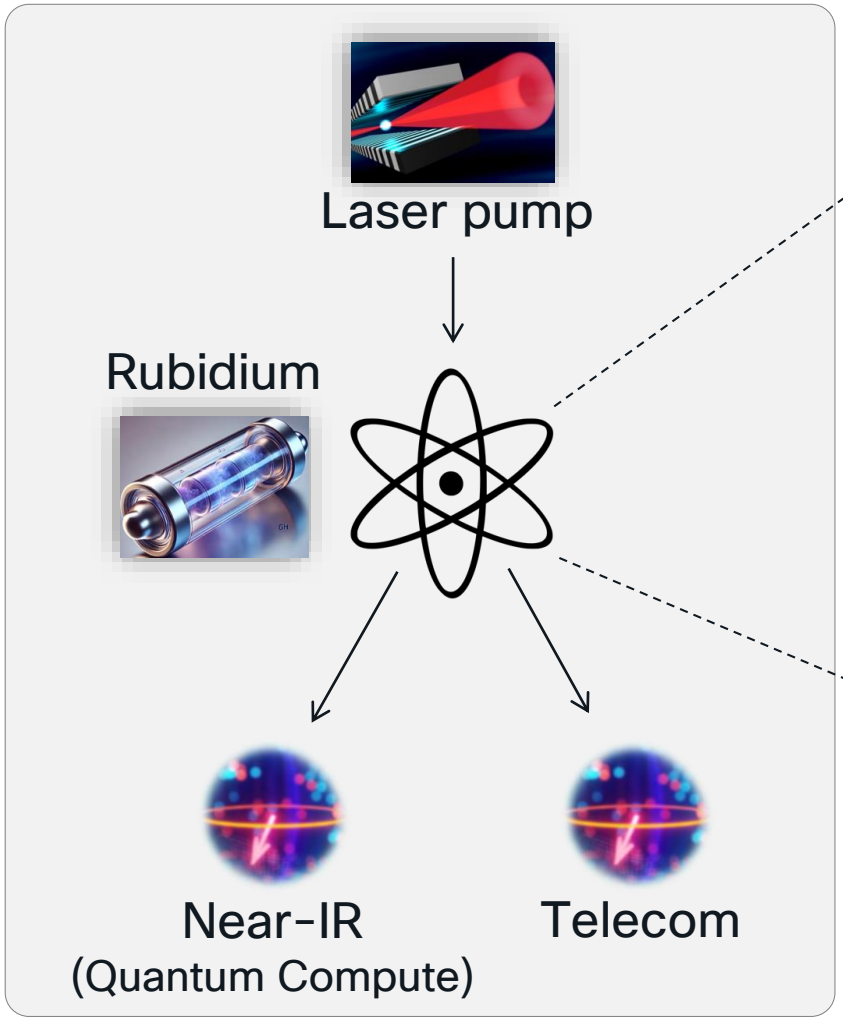
- Flying qubits are transported on photon (visible or telecom wavelength)

2 Comm Qubits vs. Data Qubits

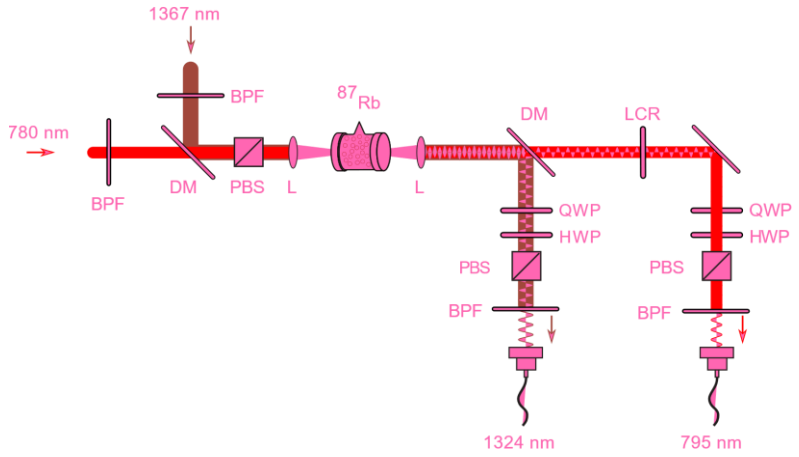


Communication qubits do NOT need to be as good as data qubits.

2 Entanglement Source for Frequency Conversion



- **High rate:** >10M pair/s
- **High fidelity:** > 99%
- **Dual frequencies:** Telecom and NIR
- **Rack mountable:** 2U form factor



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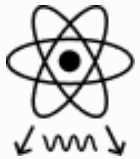
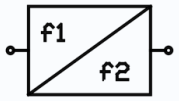
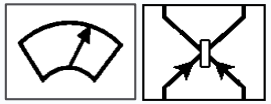


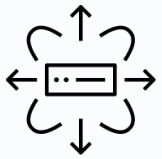
Quantum NIC



Quantum Measurement

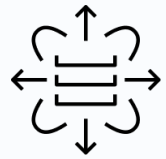


Quantum Switch

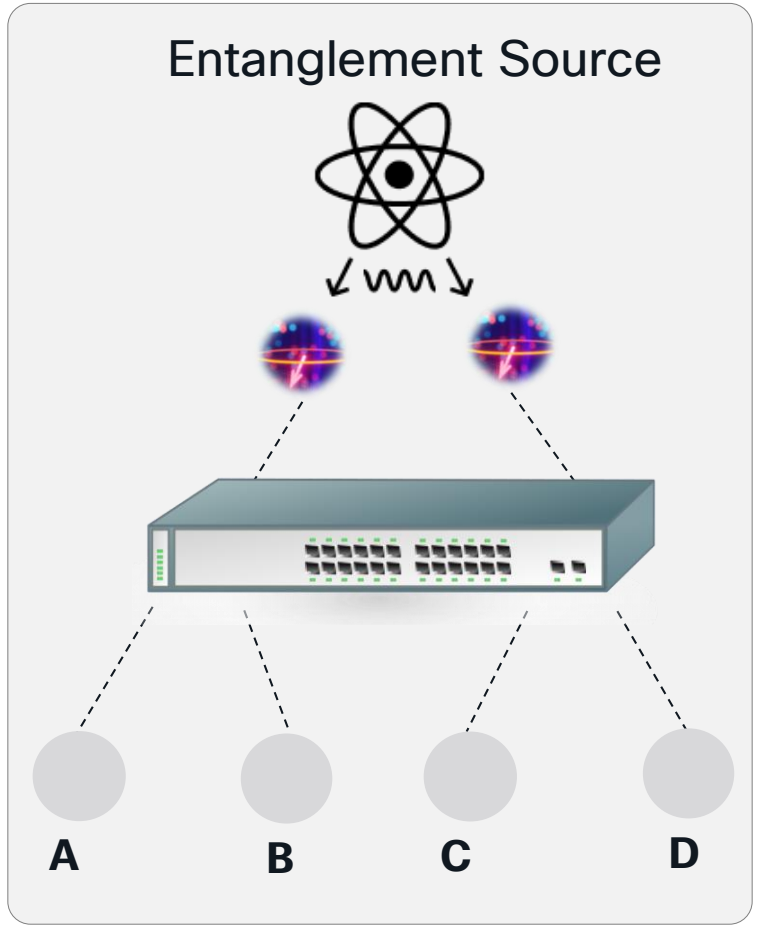


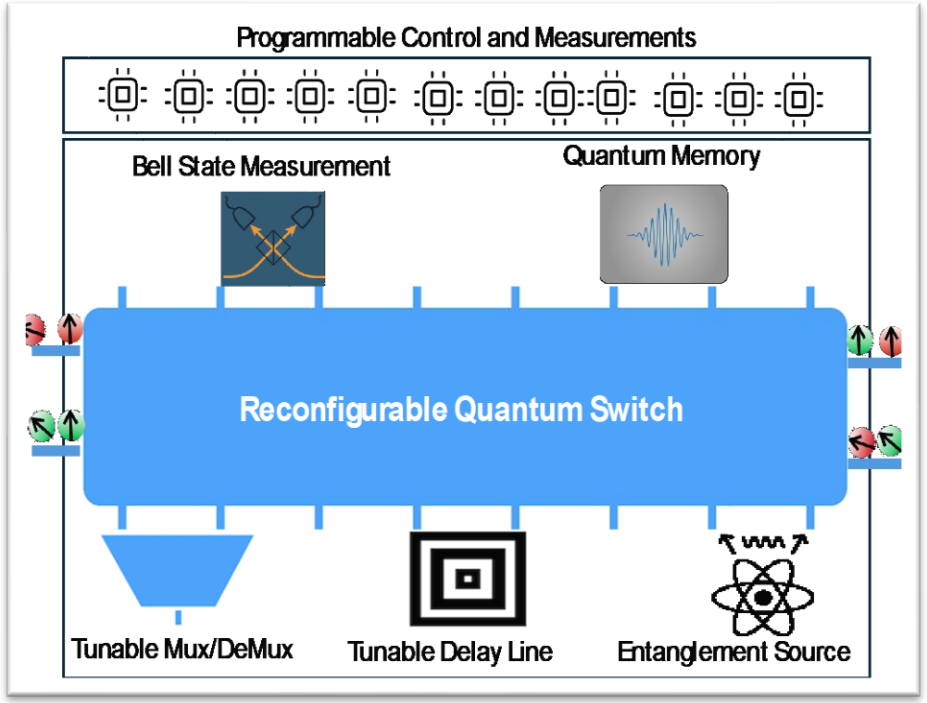
3

Quantum Memory

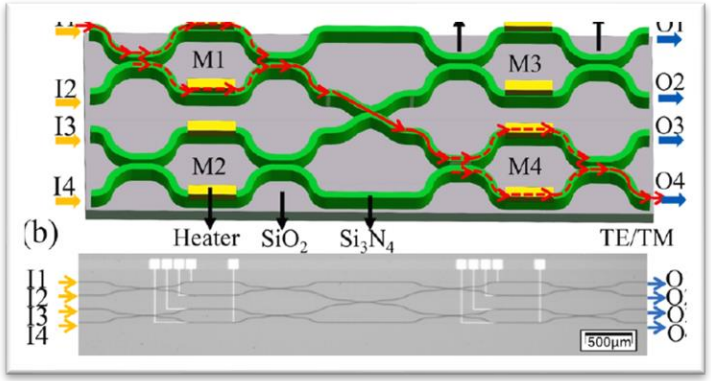


3 Quantum Switch



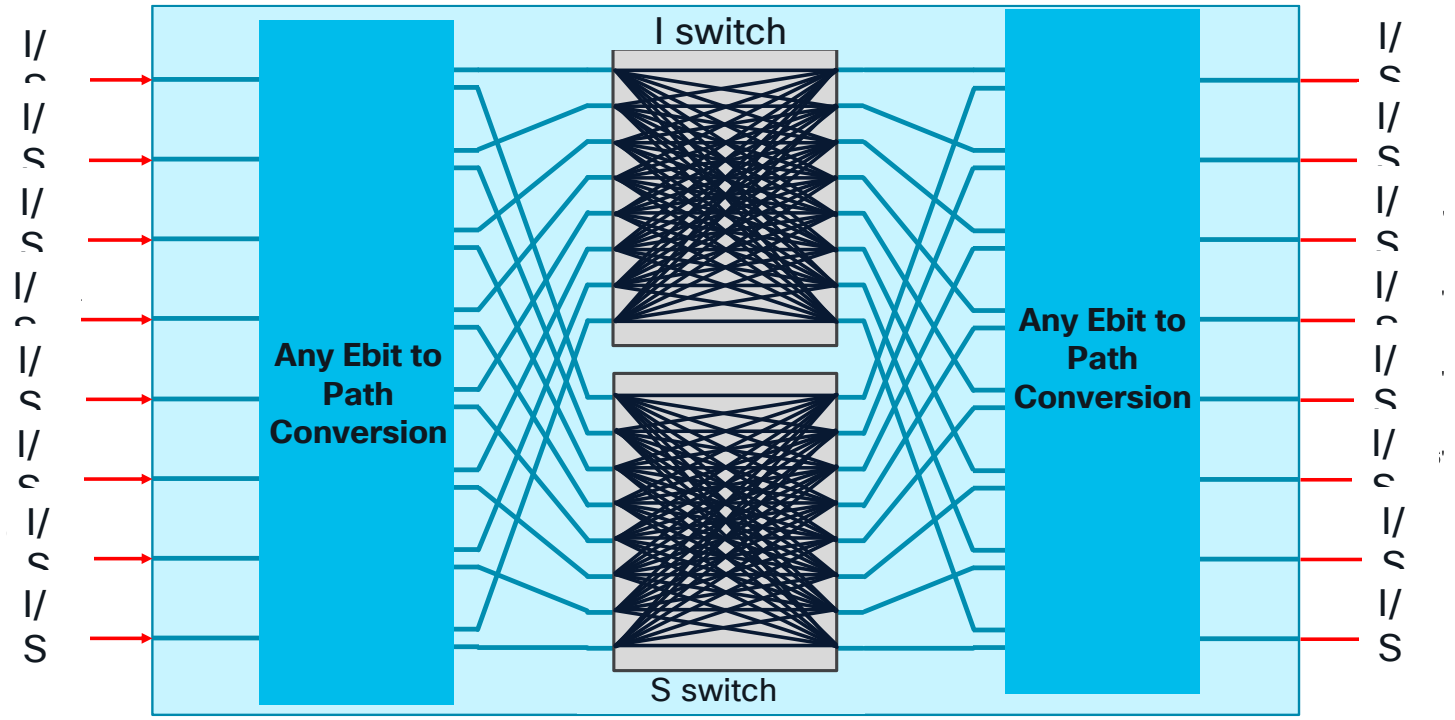


Chip (PIC) Design

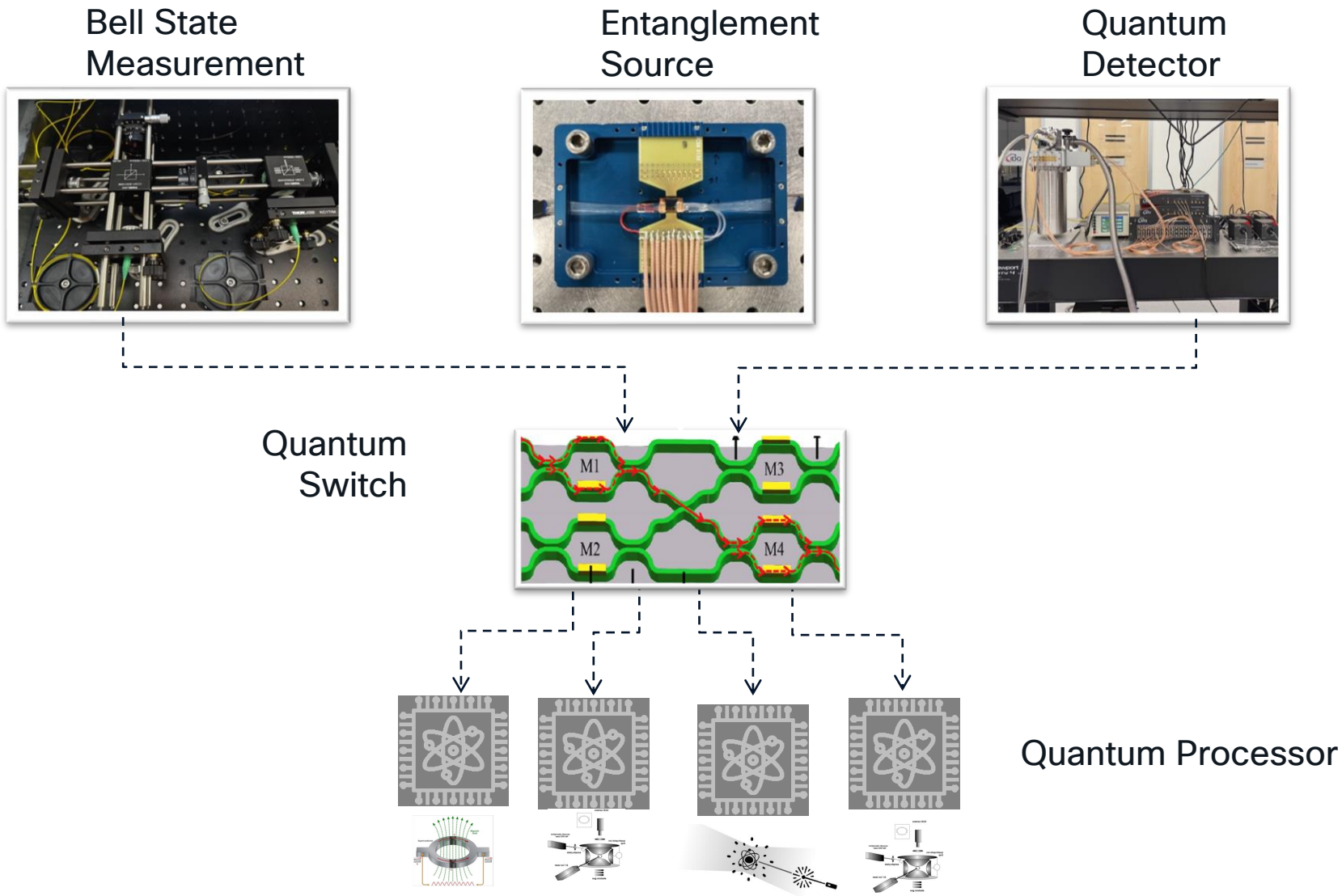


3 Quantum Switch

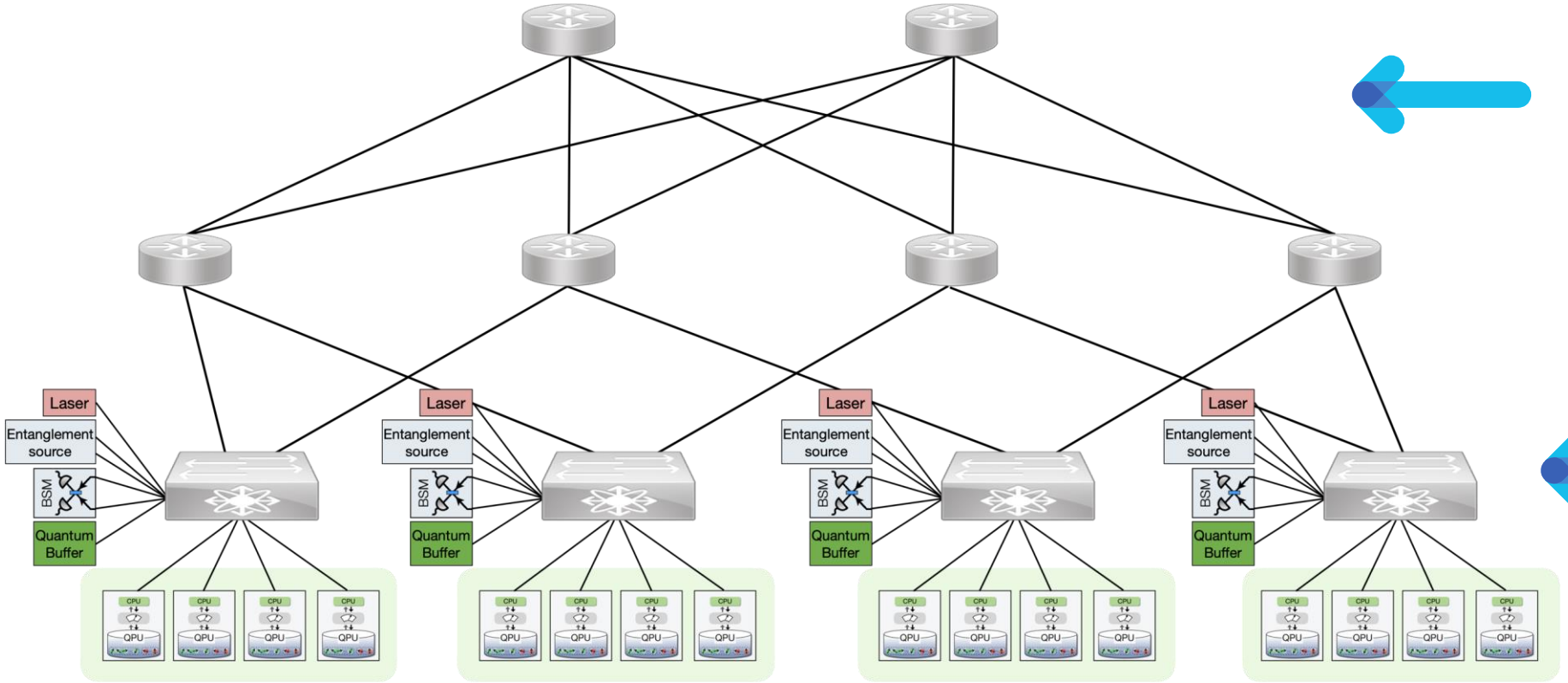
World First Quantum Switch



A Quantum Network to Share Resources



Cisco Quantum Data Center Architectures



Network Type 2:
Inter-rack network

Network Type 1:
Short-distance intra-rack network

Cisco’s Quantum Network Stack

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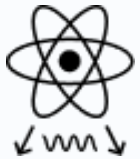
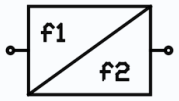
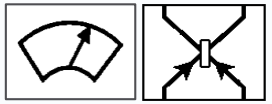
Quantum Entanglement Source



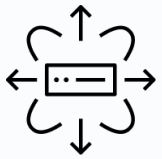
Quantum NIC



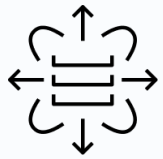
Quantum Measurement



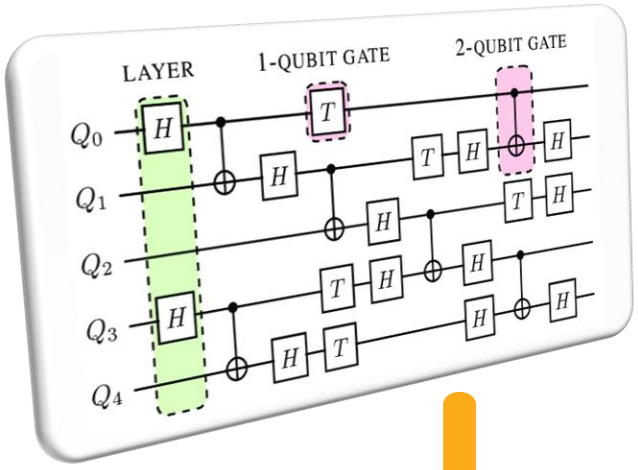
Quantum Switch

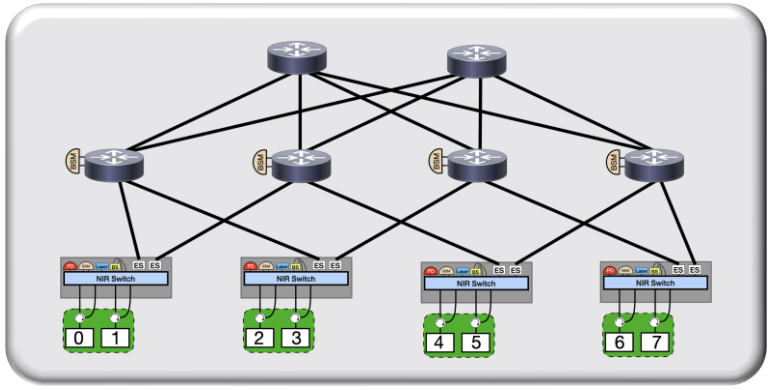


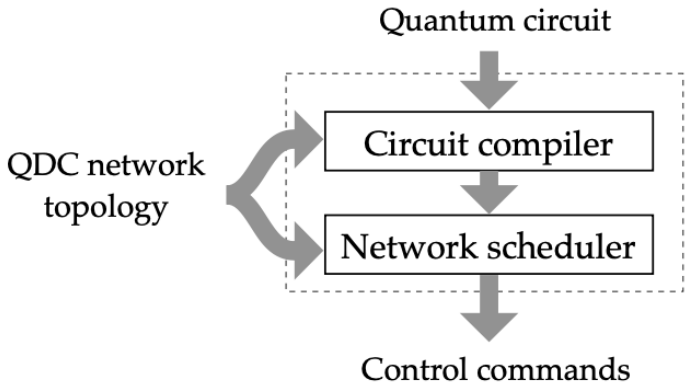
Quantum Memory



4 Cisco Quantum Data Center Orchestrator (Automation)







Circuit compiler

- Circuit Modification
- Partitioning/Rack Assignment (minimize remote gates)

Scheduler

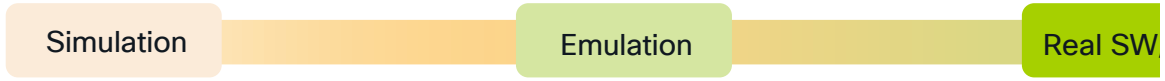
- Routing
- Resource management (minimize switching)

Instruction set to generate entanglement

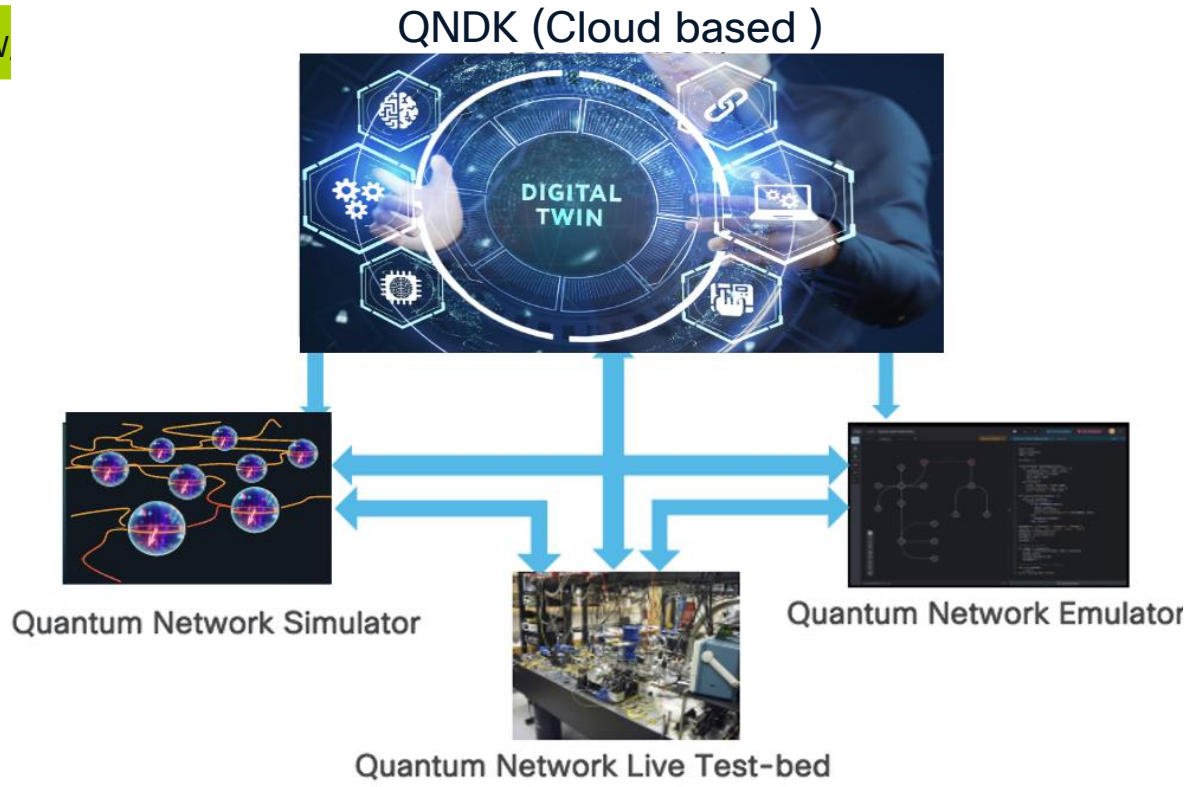
4 Cisco's Quantum Network Development Kit (QNDK)

Goal

Enable fast development, experimentation, characterization, and control of Quantum Networking hardware, software, protocols and applications

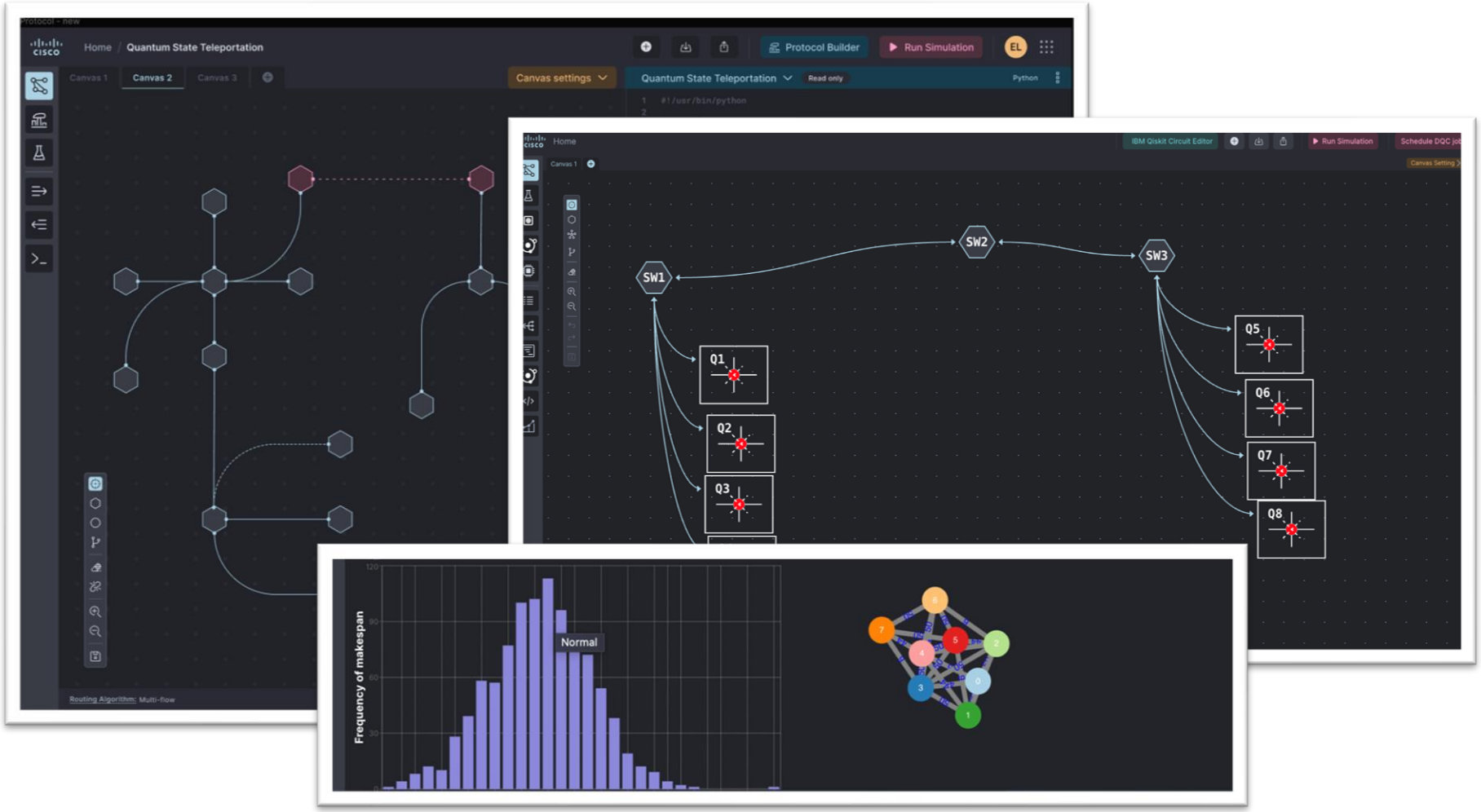


- QNDK
  - Quantum network planning tool
  - Quantum network simulation tool
  - Quantum network emulation tool
  - Feedback loop with the live Cisco quantum network test-bed
  - Up skilling and training tool for engineers



Cisco’s Quantum Network Development Kit (QNDK)

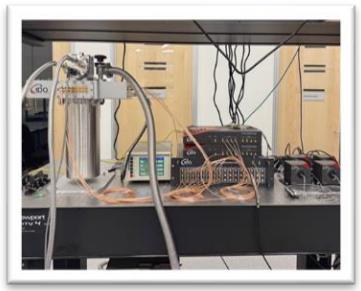
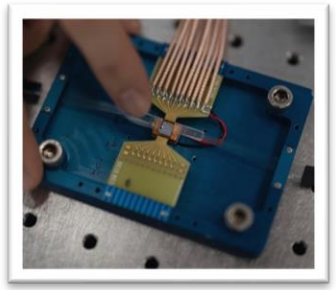
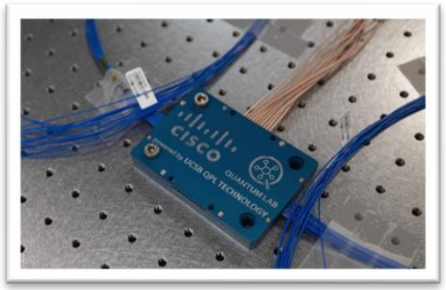
We are releasing APIs



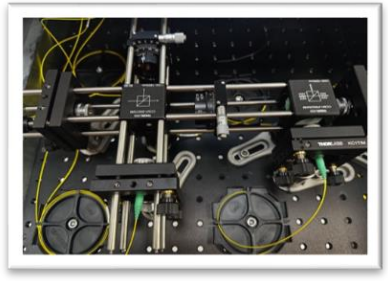
Cisco Quantum Lab

Accelerating the Impact of Quantum Computing

Cisco's advancements in **quantum networking**, combined with significant progress in quantum processors, will accelerate transformative, **scalable, practical** quantum computing within the next 5-10 years, rather than decades.

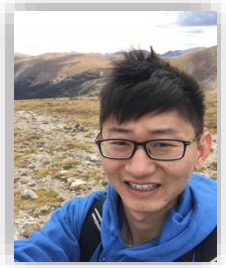




Research team + Scale of Cisco


Ramana Kompella


Reza Nejabati


Peng Zhao


Eneet Kaur


Michael Kilzer

30+ peer reviewed publications
- Nature, IEEE Magazine, IEEE Transactions, IEEE Networks, IEEE JSAC
- Flagship IEEE, OSA, OPTICA, ACM confs.

20+ Patents

- **Practical** quantum computing can only be achieved via **scaling-out** as opposed to just scaling-up

- Cisco is researching and developing components, software, systems to create a high-fidelity **entanglement**-based quantum network

+Outshift team
+Our optics and photonics group
+Security business group
+Security and Trust Organization
+More than 10 universities, industry organizations

Data Center Network Architecture

- **Quantum Data Center Infrastructures: A Scalable Architectural Design Perspective**
- **Optimizing Quantum Communication for Quantum Data Centers with Reconfigurable Networks**
- **Quantum network planning for utility maximization**

Compilers and Protocols

- **Optimized Quantum Circuit Partitioning Across Multiple Quantum Processors**
- **Entanglement Request Scheduling in Quantum Datacenter Networks**
- **Resource Placement for Rate and Fidelity Maximization in Quantum Networks**
- **Minimal Protocols for Entanglement Distribution with Finite Memory Coherence Time**
- **Analysis of Asynchronous Protocols for Entanglement Distribution in Quantum Networks**
- **Asynchronous entanglement routing for the quantum internet**

Physical layer

- **Scalable MHz rate entanglement distribution in a heterogeneous quantum network with reduced latency**
- **Continuous entanglement distribution via time-multiplexed entanglement source and BSM**
- **Photonic One-Way Quantum Repeater**
- **MECH: Multi-entry communication highway for superconducting quantum chiplets**
- **Bipartite entanglement of noisy stabilizer states through the lens of stabilizer codes**

4 Key Takeaways

1. Quantum networking is **completely different** from classical networking
2. Though scale-up quantum computing could be X years out, quantum networks can **accelerate** the arrival of practical quantum computing by 5–10 years
3. Quantum networking has many **practical** and commercial use cases in the **classical** world **today**
4. We are building a **practical** and **scalable** Quantum Network

Demo 1

cisco Live !

Demo 2 (Live)

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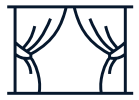

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