AI for Good
Discovery

Webinar

Quantum networking: Issues, challenges and opportunities



Speaker

Raj Jain

Washington University, St Louis, USA

Presented and organized by

ITU Journal
Future and evolving technologies



24 March 2026
16:00 - 17:30 CET/UTC +1

50+ UN PARTNERS

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1. Why Quantum?
2. What is Quantum
3. How to do Quantum Networking
4. Standards Activities
5. Challenges and Myths

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Part 1: Why Quantum?

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Selecting the Right Research Topic/Field

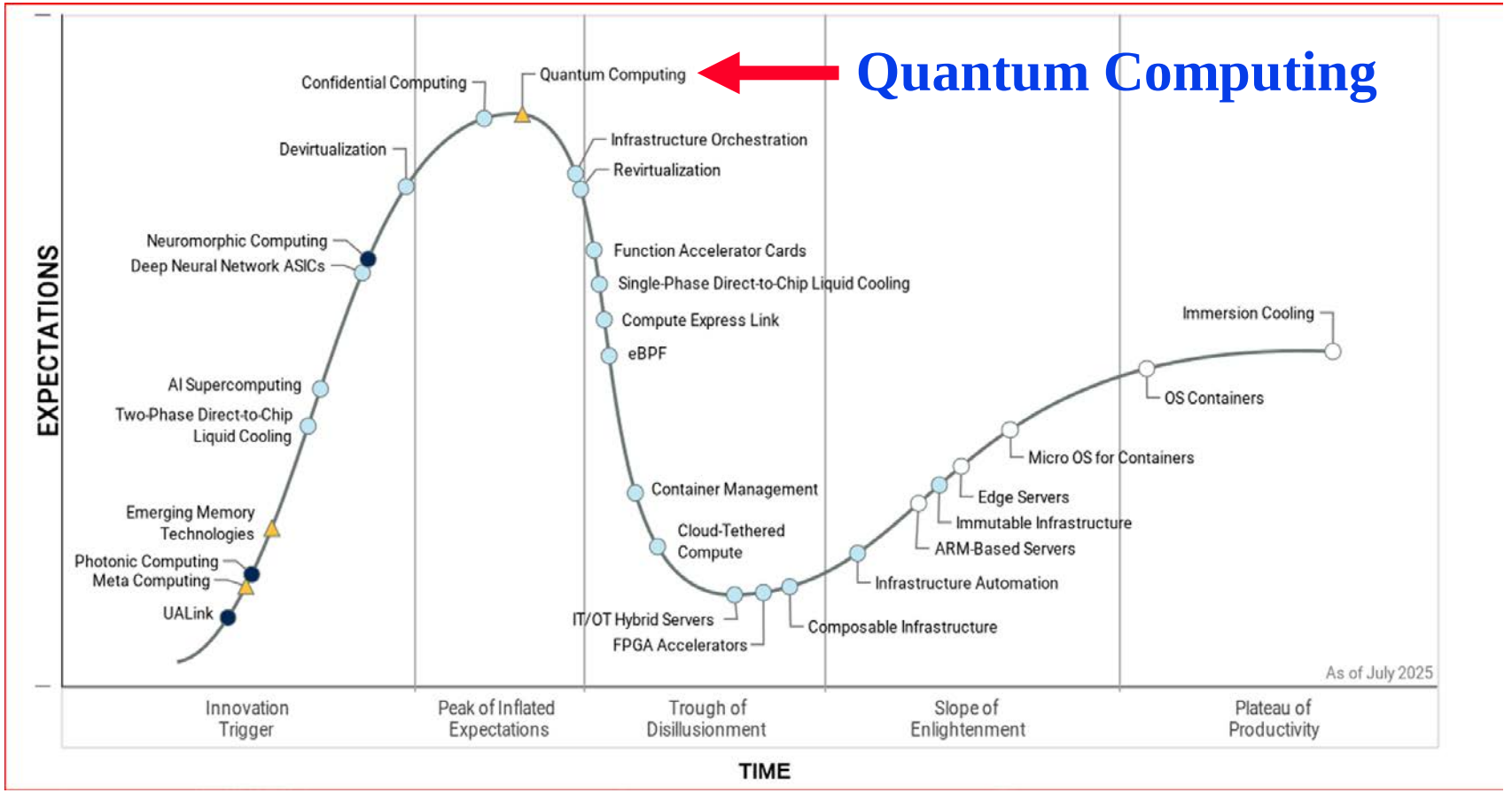
- An important question for students, academics, entrepreneurs, and companies
- Most academics follow the herd or stick to their old expertise.
- Goal: To impact ⇒ Follow the **paradigm shifts**:
  - 2008: Next Generation Internet/SDN
  - …
  - 2025: Whatever is being **hyped** this year?
- The United Nations has declared 2025 the International Year of Quantum Science and Technology.
  https://quantum2025.org





Industries adapt by necessity.
Academics continue to dwell deeper in what they already know.

Hype Cycle for Compute 2025

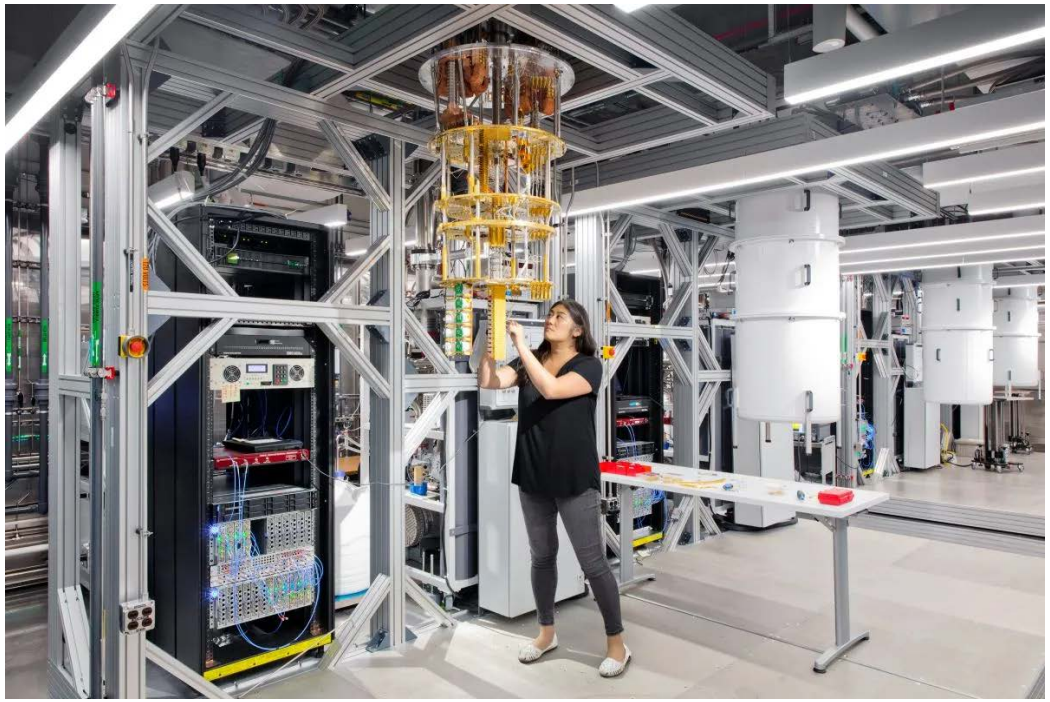


This is the right time to get into Quantum.

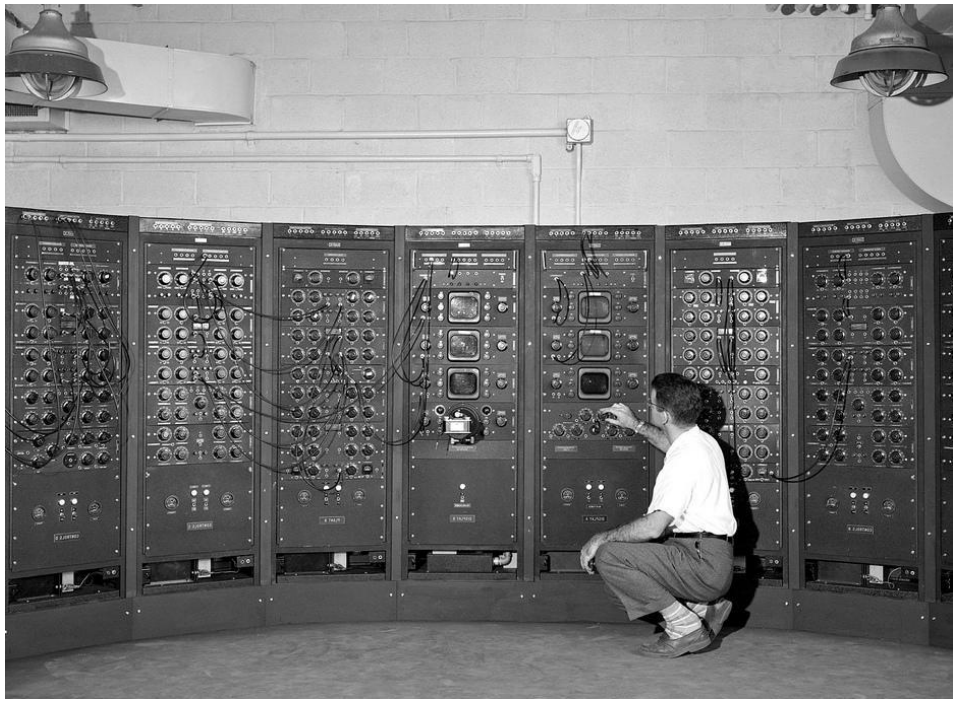
Ref: T. Harvey, "Hype Cycle for Compute, 2025," Gartner Report ID G00832015, July 1, 2025, 98 pp. (Available via subscription)

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Dawn of Quantum Computing



IBM's Quantum computer



ENIAC (1946)

Ref: https://www.zdnet.com/article/what-is-quantum-computing-everything-you-need-to-know-about-the-strange-world-of-quantum-computers/

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IBM Quantum System Two



October 2024

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Investment in Quantum

- $40-55 billion in the Asia-Pacific region (APAC)
- China alone accounts for $15 billion in public investment in quantum:
  - A $138B government-backed venture fund for tech, including quantum
  - University of Science and Technology of China (USTC)
    Chinese Academy of Sciences (CAS), National Development Reform Commission (NRDC)
- European Union (including Germany, France, and the UK) over $10B
- US Federal Government $5-6 B
- The private sector investments are many times more than the public expenditure above.
- Google, IBM, Microsoft, Amazon, and Cisco are all invested.

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US Investments in Quantum

- NIST, NSF, DOE, DOD, NASA, NSA, and IARPA (Intelligence ARPA) – all coordinated by the National Quantum Coordination Office (NQCO).
- Illinois has set up a Quantum Park in Chicago. Has invited Cisco, IBM, Google, and other companies to set up there.
- **DC-Qnet:**
  - A Consortium of US government agencies in the Washington DC area: NIST, NRL. ARL, USNO, NSA, NASA, and AFRL.
  - Goal: to build and operate a functional quantum network
  - Uses existing fiber network over metropolitan distances
- Other testbeds: DOE's Quantum Garage, QUIET/LOUD facilities, and NSF's National Quantum Nanofab (NQN)

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Impact of Quantum Computing on Security

- Current Security Methods are largely based on RSA, which is based on the difficulty of factorization of large numbers
- As the computers become faster, we keep increasing the key size: RSA-1024, RSA-2048, …
- **Quantum Threat**: Peter Shor showed in 1994 that quantum computers can factorize numbers exponentially faster than legacy computers.

Adopt quantum-safe security.

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Post-Quantum Cryptography

- The National Institute of Standards and Technology (NIST) has finalized:
  - **FIPS 203: ML-KEM**: Based on CRYSTALS-Kyber (lattice-based), replaces RSA and ECC for secure key distribution.
  - **FIPS 204: ML-DSA**: Based on CRYSTALS-Dilithium for digital signatures.
  - **FIPS 205: SLH-DSA**: Based pm SPHINCS+ for hash-based signatures. For long-term integrity in archival and regulatory environments
  - **FIPS 206: FN-DSA**: Based on FALCON (also lattice-based) is in draft stage
- Hardware vendors have incorporated quantum-resistant algorithms:
  - Trusted Platform Modules (TPMs), Hardware Security Modules (HSMs)

PQC will help you protect from "Harvest Now Decrypt Later" Attacks.

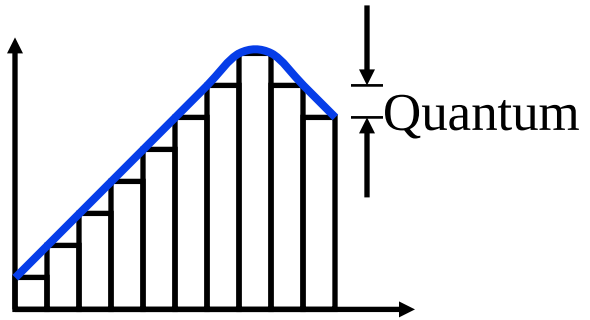
Ref: Post-Quantum Cryptography Coalition, https://pqcc.org

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Part 2: What is Quantum?

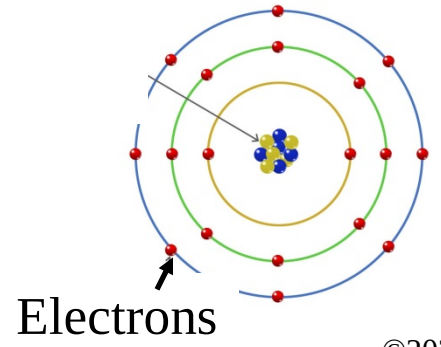
What is a Quantum?

- Quantization: Analog to digital conversion
- Quantum = Smallest discrete unit
- **Wave Theory**: Light is a wave. It has a frequency, phase, and amplitude
- **Quantum Mechanics**: Light behaves like discrete packets of energy that can be absorbed and released
- **Photon** = One quantum of light energy
- Photons can move an electron from one energy level to the next higher level
- Photons are released when an electron moves from one level to a lower energy level





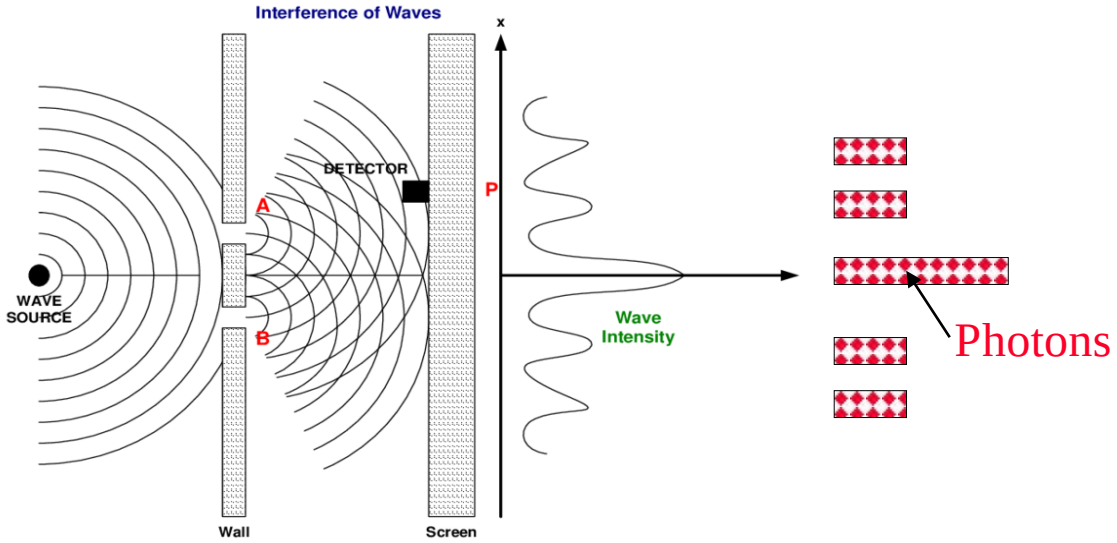




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Are Photons Particles or a Wave?

- Young's Double-Slit Experiment 1801



- The two waves exiting the slits interfere.
- Einstein showed that light consists of photon particles.
- Photons are both particles and waves. Are electrons both too?

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Quantum Bits

1. Computing bit is a binary scalar: 0 or 1
2. Quantum bit (**Qubit**) is a 2×1 **vector**, e.g., $\begin{bmatrix}1\\0\end{bmatrix}$ or $\begin{bmatrix}0\\1\end{bmatrix}$ or $\begin{bmatrix}\alpha\\\beta\end{bmatrix}$ or $\begin{bmatrix}\frac{1+2i}{i\sqrt{6}}\\\frac{1-2i}{i\sqrt{6}}\end{bmatrix}$
3. Two qubits are represented by 4×1 vector, e.g., $\begin{bmatrix}0\\0\\0\\1\end{bmatrix}$ or $\begin{bmatrix}1\\0\\1\\0\end{bmatrix}$ or $\begin{bmatrix}\frac{2+i}{i\sqrt{6}}\\\frac{2-i}{i\sqrt{6}}\\\frac{1+i}{i\sqrt{6}}\\\frac{1-i}{i\sqrt{6}}\end{bmatrix}$

While computing bits are scalars, quantum computing bits are vectors.

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Dirac Bra-Ket Notation

- Brackets: { }, [ ], < >
- The vectors are denoted as bra or kets
- Bra <a| is a row vector: $\begin{bmatrix}1 & 0\end{bmatrix} = <0|$ $\begin{bmatrix}0 & 1\end{bmatrix} = <1|$
- Ket |a> is a column vector: $\begin{bmatrix}1\\0\end{bmatrix} = |0>$ $\begin{bmatrix}0\\1\end{bmatrix} = |1>$
- A qubit can be represented as a combination: $\begin{bmatrix}\alpha\\\beta\end{bmatrix} = \alpha\begin{bmatrix}1\\0\end{bmatrix} + \beta\begin{bmatrix}0\\1\end{bmatrix} = \alpha|0> + \beta|1>$
- Two qubits: $|\psi> = \alpha|00> + \beta|01> + \gamma|10>| + \lambda|11>$

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Superposition

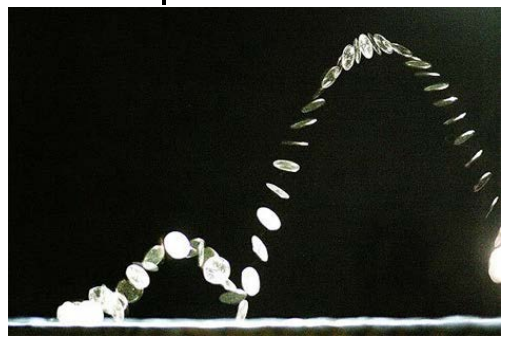
- Qubits are probabilistic. The elements of the vector indicate the probability amplitude.

$$\begin{bmatrix}\alpha\\ \beta\end{bmatrix} = \alpha\begin{bmatrix}1\\ 0\end{bmatrix} + \beta\begin{bmatrix}0\\ 0\end{bmatrix}$$

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

- The qubit $\begin{bmatrix}\alpha\\ \beta\end{bmatrix}$ has a probability $\frac{\alpha^2}{\alpha^2+\beta^2}$ of being *measured* in the |0> state and a probability $\frac{\beta^2}{\alpha^2+\beta^2}$ of being *measured* in the |1> state.
- Until it is measured, its state is undetermined.

This is called **superposition** (like a coin in flight during flips).



Qubits are in superposition until measured.

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No-Cloning Theorem

- You cannot create a perfect copy of an arbitrary, unknown quantum state.
- So if you have a qubit $|\psi>=\alpha|0>+\beta|1>$
- If you measure it, you get a |0> or |1> but loose α and β
- Since no backup copy could be made, the qubit is permanently lost.
- If anyone on the way reads a qubit, the receiver will know.
- Quantum link is more secure than classical links to transfer highly secure information such as encryption keys.

Eve-droppers are easily detected in quantum communication

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Entanglement



Both think the same

- Two qubits can be entangled ⇒ Their states are correlated
  - Momentum, spin, polarization, or position are correlated
  - Even when they are far apart
  - Any change of one qubit affects the other
    ⇒ Teleportation of state ⇒ Quantum Key Distribution
- 1935: Einstein called it a paradox since change seems to happens at a speed faster than light
- 2022: Physics Nobel Prize for experiments with entangled photons

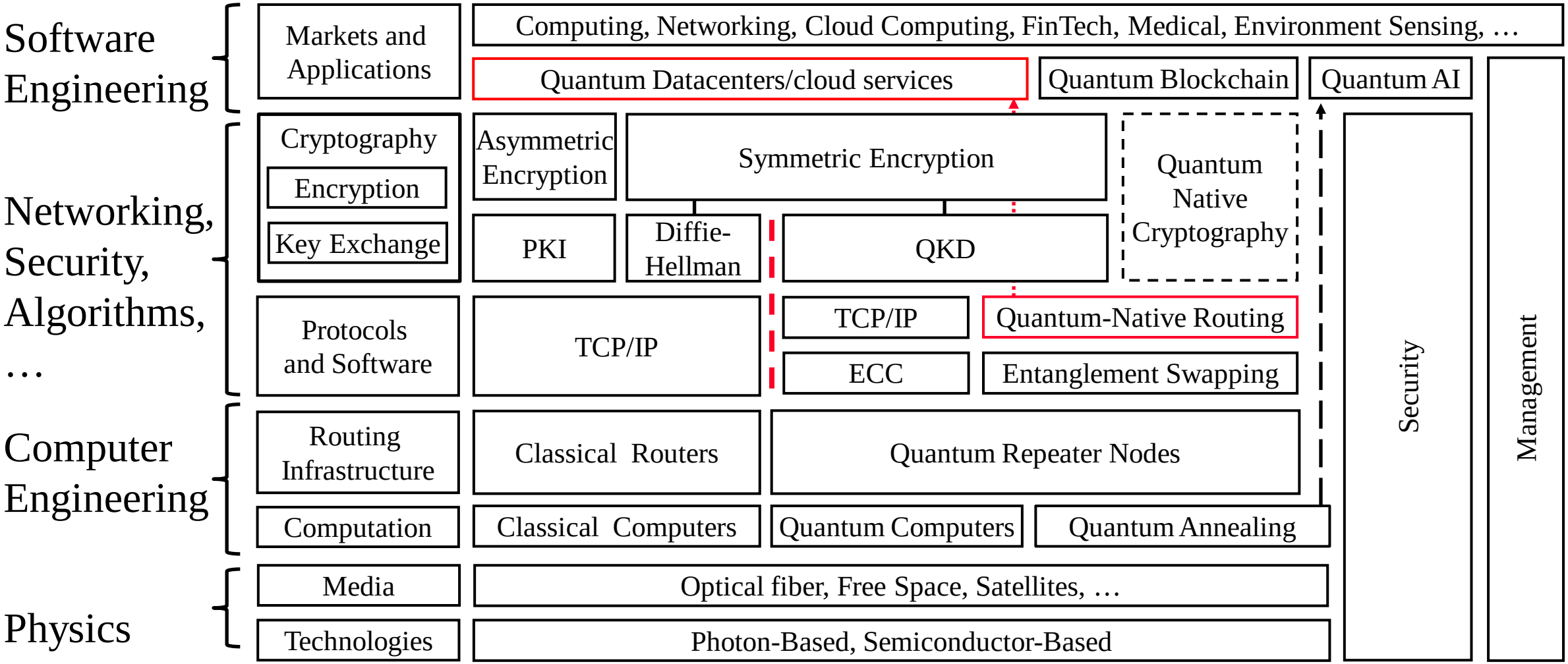
Entanglement allows communication via qubits.

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Part 3: How to do Quantum Networking?

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7-Layers Stack of Quantum Research

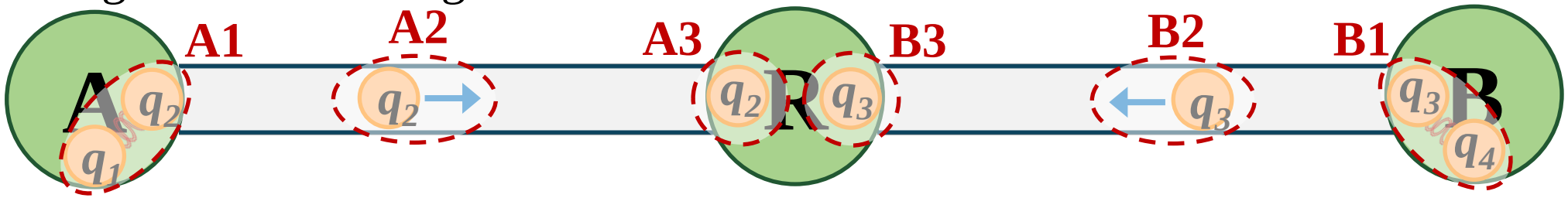


Quantum research is dominated by the physics department.

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Simplest Quantum Network via Entanglement Swapping

- Entanglement for a long distance.



A1 / B1: Local Pair Generation:

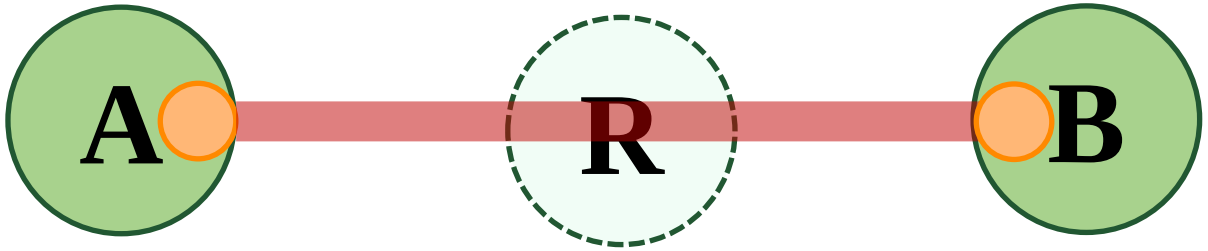
- Node A generates an entangled photon pair (q_1, q_2)
- Simultaneously, Node B generates an entangled photon pair (q_3, q_4)

A2 / B2: Flying Qubit Transmission:

- Node A keeps q_1 and sends q_2 as a flying qubit toward the repeater.
- Node B keeps q_4 and sends q_3 as a flying qubit toward the repeater.

The Swapping Operation:

- At this point, A-R and B-R are entangled.
- Repeater R performs a Bell State Measurement (BSM) on the two qubits it currently holds.
- Following the BSM and classical signaling of results, q_1 and q_4 become instantaneously entangled:

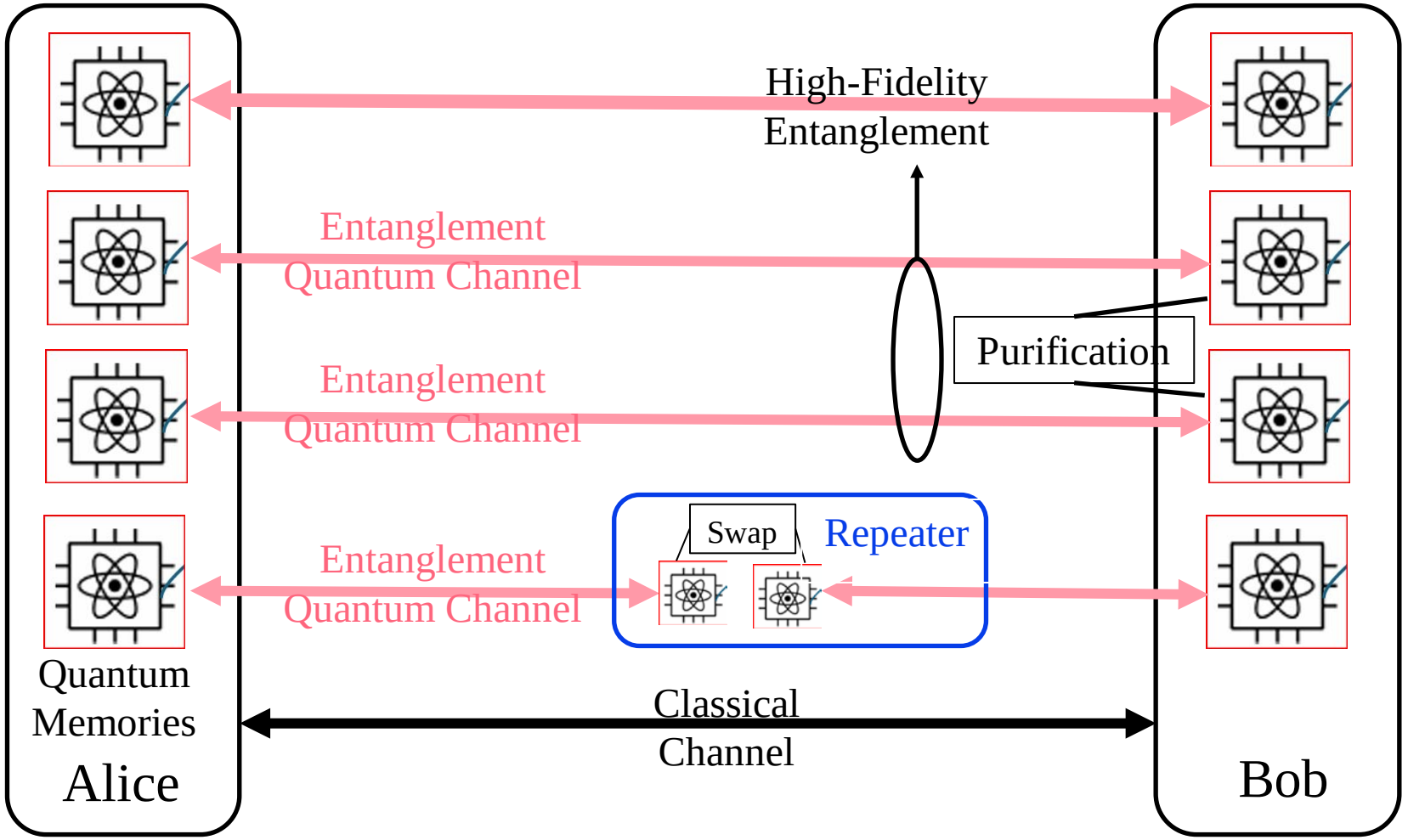


Nodes separated by multiple hops can exchange secrets using entanglement swapping

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Networking Components and Functions

- **Memories**: Hold Qubits
- **Repeaters**: Swap two entanglements to create one longer entanglement
- **Purification**: Combines two or more entangled qubits to create a logical qubit with higher fidelity
- **Classical Channel**: Non-quantum channel. Used for signaling
- Hybrid communication



Ref: NIST, "**Entanglement Routing in Quantum Networks: A Comprehensive Survey**," 2025, https://www.nist.gov/publications/entanglement-routing-quantum-networks-comprehensive-survey

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Challenges in Quantum-Native Networking

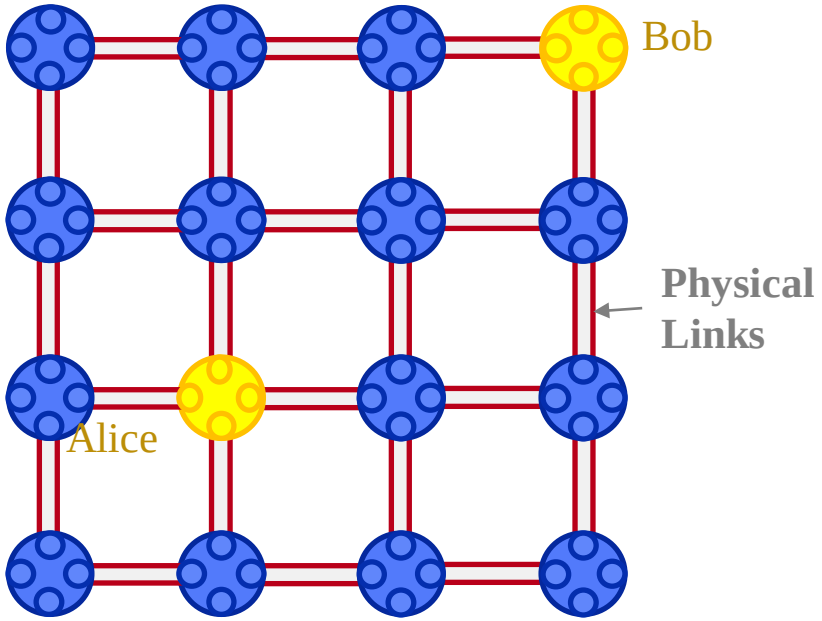
1. Entanglement of a link is destroyed once the data is transmitted.
   ⇒ Need to reestablish remote entanglement for each use.
2. Qubit is lost at the sender due to measurement.
3. De-coherence: Qubits are lost quickly (ranging from μs to s).
   ⇒ Entanglement can decohere.
   ⇒ The transmission must happen and finish within the coherence time.
4. There is a possibility that the entanglement attempt fails.
   ⇒ Availability of a link between two nodes is probabilistic.
   ⇒ Paths may change with every attempt.
5. The correlation among entangled bits is not perfect ⇒ Fidelity
6. Fidelity can be improved by combining many entangled bits ⇒ Purification

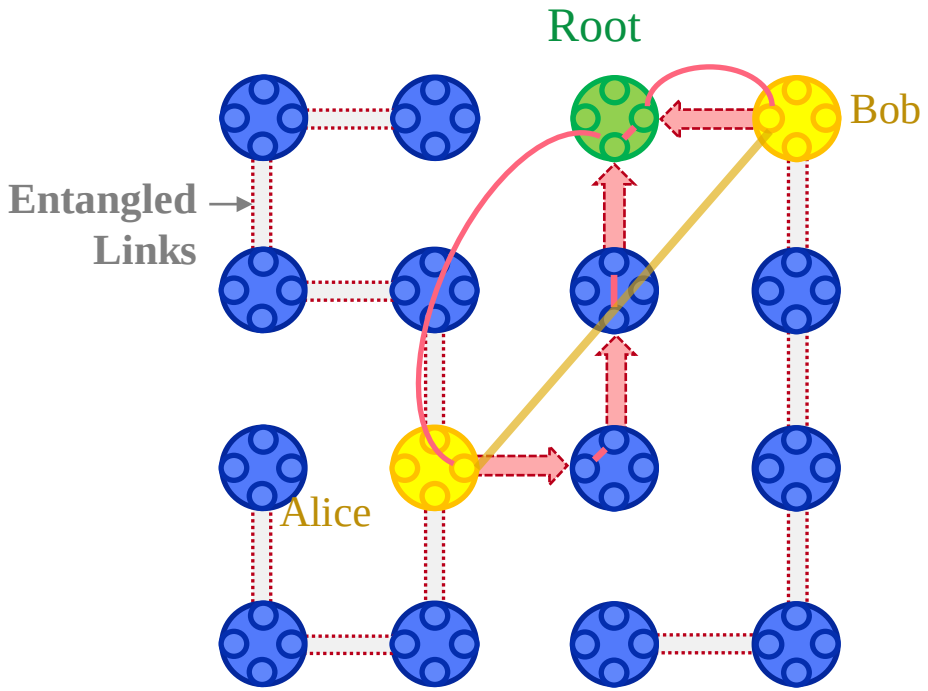
Ref: Z. Yang, M. Zolanvari and R. Jain, "A Survey of Important Issues in Quantum Computing and Communications," in IEEE Communications Surveys & Tutorials, doi: 10.1109/COMST.2023.3254481.

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Routing Problem

- Objective: Establish entanglement between source-destination pairs
- Constraints: Probabilistic entanglement generation, decoherence
- Performance Metrics: Throughput (end-to-end entanglements/sec), fidelity, latency, and resources used.

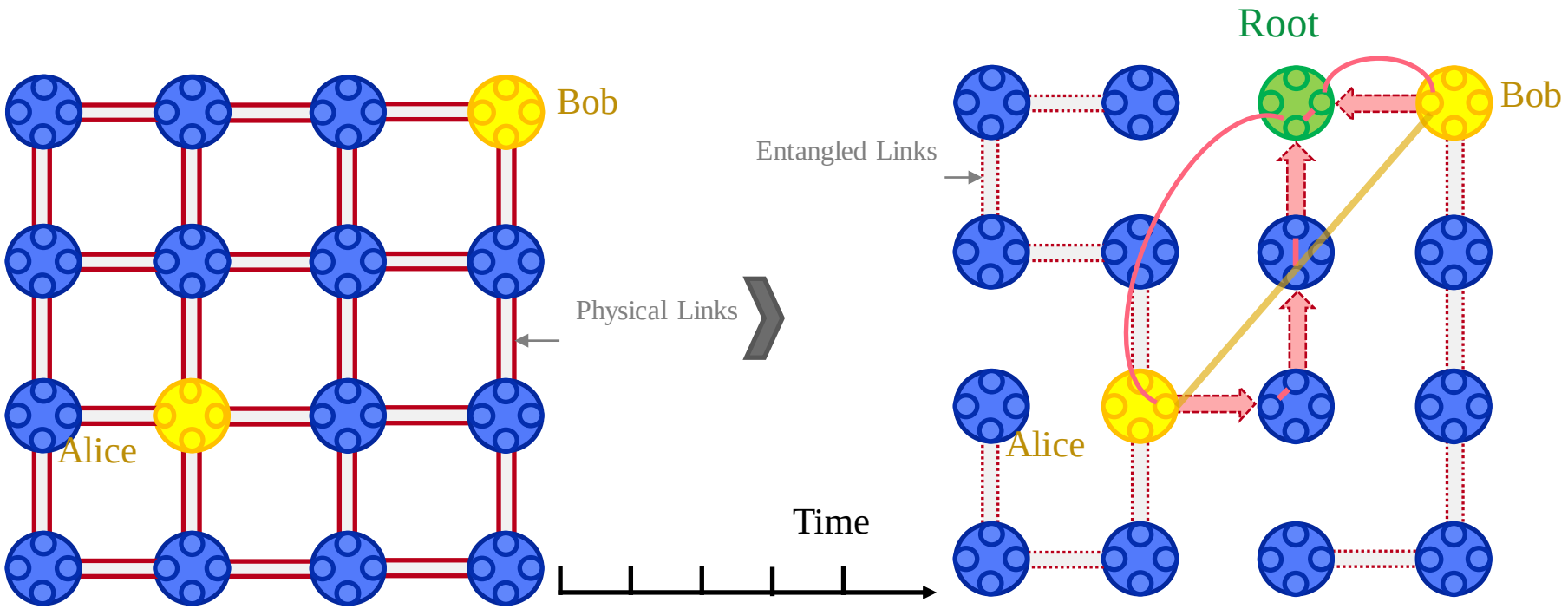




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Synchronous vs Asynchronous

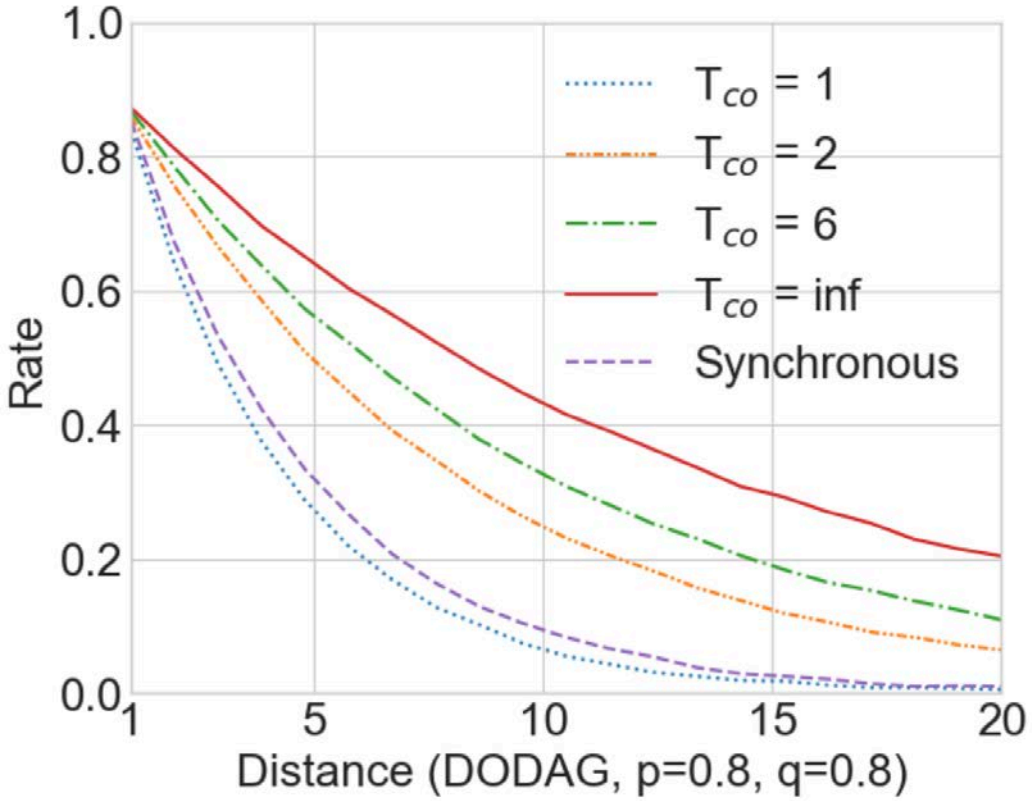
- Many researchers divide the time into slots ⇒ Synchronous operation
- We proposed an Asynchronous Entanglement Routing (**AER**) scheme using DODAG or a spanning tree, similar to RPL used in the Internet of Things and Ethernet Spanning Tree.

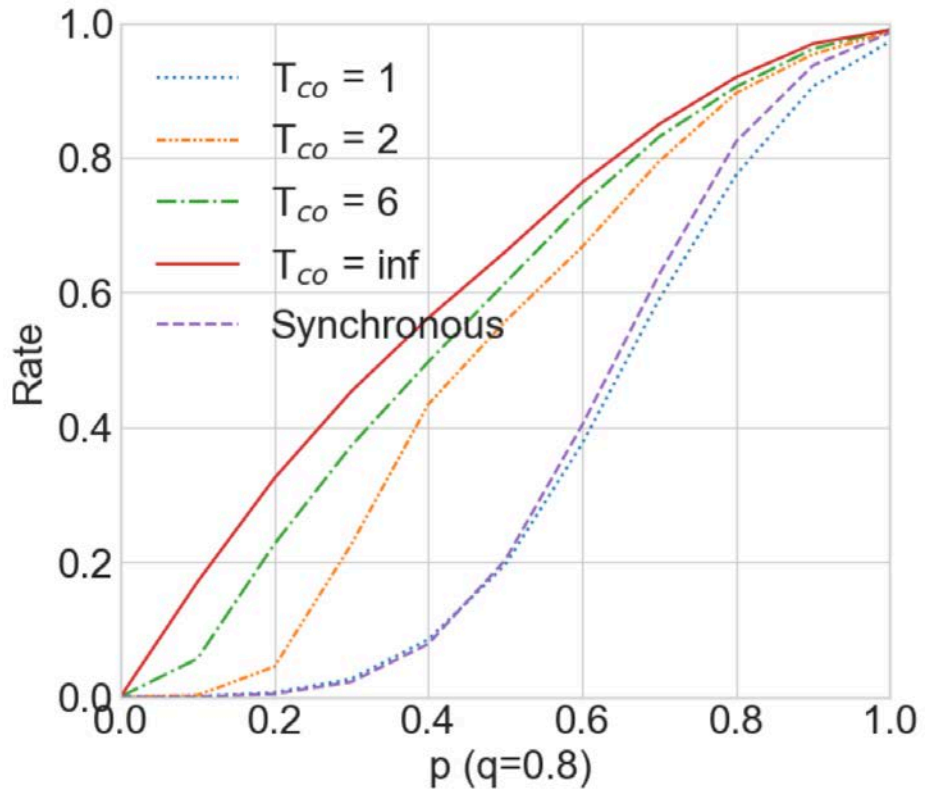


Ref: Zebo Yang, Ali Ghubaish, Raj Jain, and H. Shapourian, "**Asynchronous Entanglement Routing for the Quantum Internet**," AVS Quantum Sci. 6, 013801, Jan 2024, http://www.cse.wustl.edu/~jain/papers/qrout.htm

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AER Analysis and Simulation



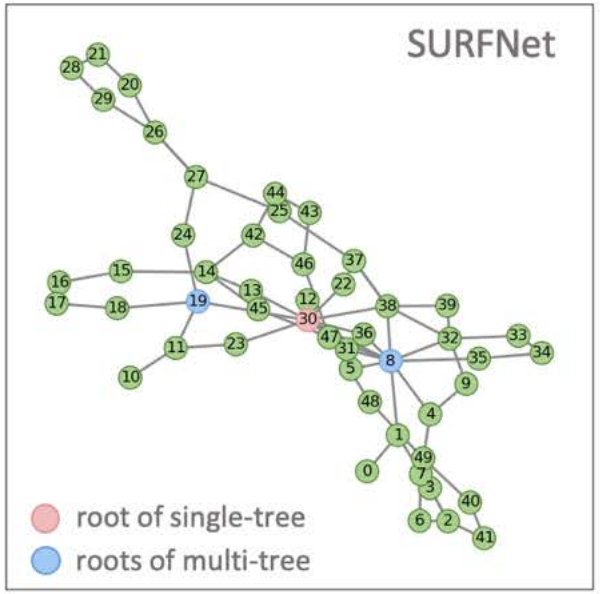


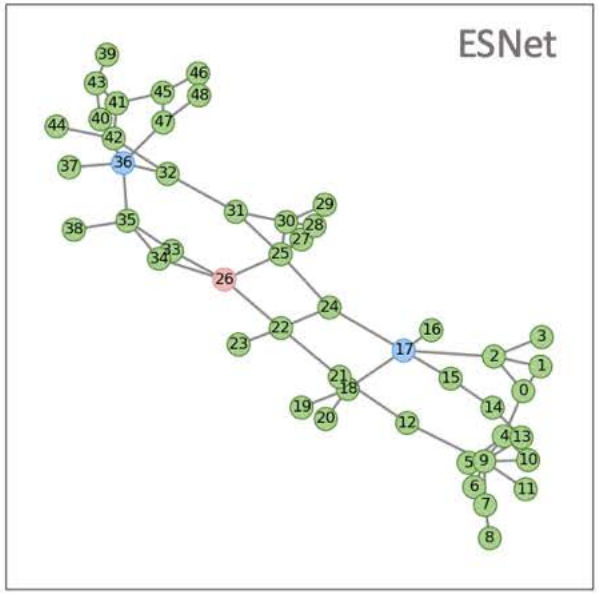
p: direct-link entanglement generation success rate; **q:** entanglement swapping success rate; **T_{co}:** coherence time

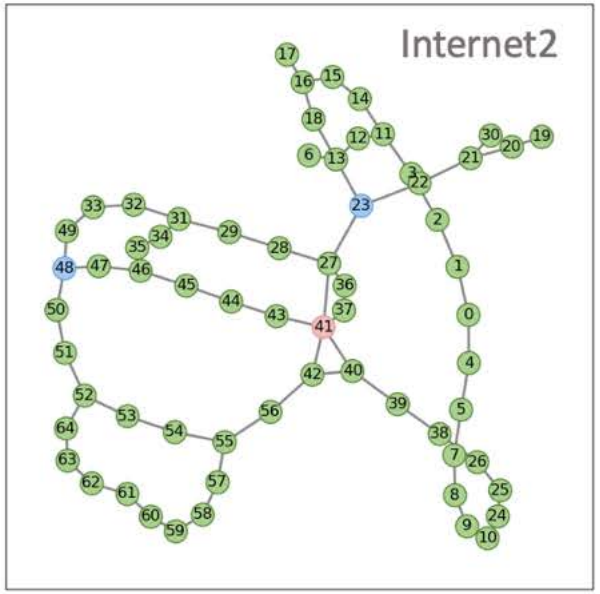
The end-to-end entanglement rate of asynchronous routing increases with the coherence time, decays slower, and is generally larger than synchronous approaches.

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Realistic Topology Experiments







- The three topologies have different structures:

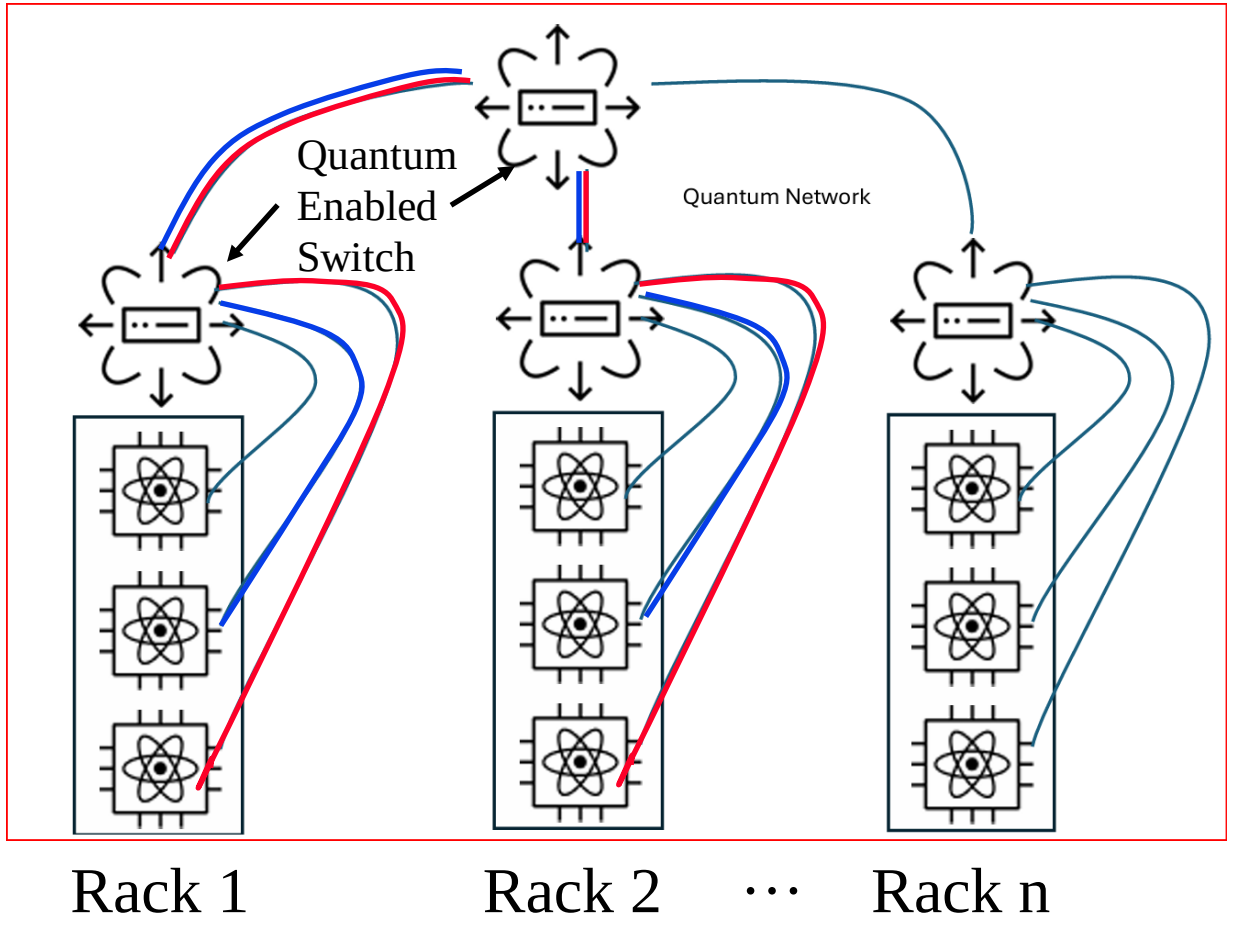
1. SURFNet has nodes with strong connections, making them suitable candidates for root nodes.
2. ESNet exhibits less densely distributed nodes and fewer highly connected central nodes
3. Internet2 includes long linear chains in its topology.

Ref: Zebo Yang, Ali Ghubaish, Raj Jain, Ramana Kompella, and Hassan Shapourian, "**Multi-Tree Quantum Routing in Realistic Topologies**," IEEE Communications Magazine, Vol. 62, No. 10, October 2024, pp. 78-85, http://www.cse.wustl.edu/~jain/papers/multitree.htm

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Routing in Quantum Data Centers

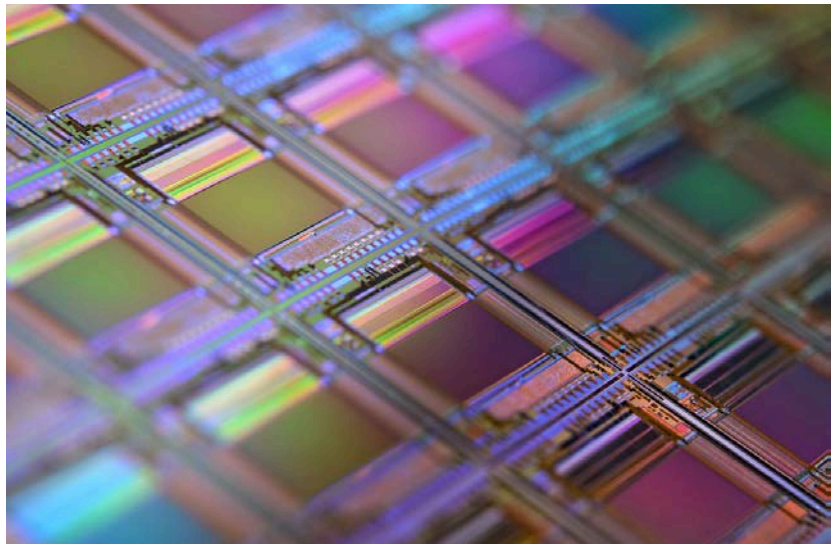
- Consider an example data center with *n* racks as shown here. Each rack contains several QPUs and a Quantum-Enabled Switch.
- The lines indicate fiber bundle links. Each bundle may support multiple entangled qubit pairs, leading to varying capacities.
- Quantum jobs require a path between their source and destination QPU.
- If more than one job needs the same link, it has to be **fairly** and **efficiently** shared.



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Clusters of Quantum Processing Units (QPUs)

- Noise in QPUs increases significantly as the number of qubits increases
- One way to make larger processors is to cluster several smaller QPUs together.
- Many QPUs on the same chip are interconnected via optical waveguides
- Short-range (cm to m), high-fidelity, shared clocking and phase reference, high-rate entanglement distribution between QPUs, no repeaters
- Multi-QPU error correction



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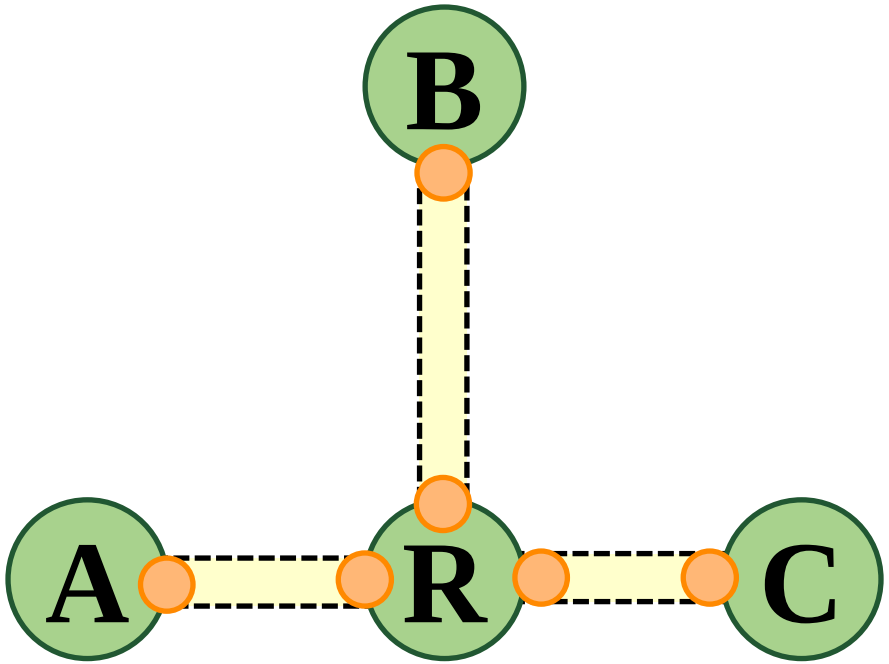
Types of Routing Algorithms

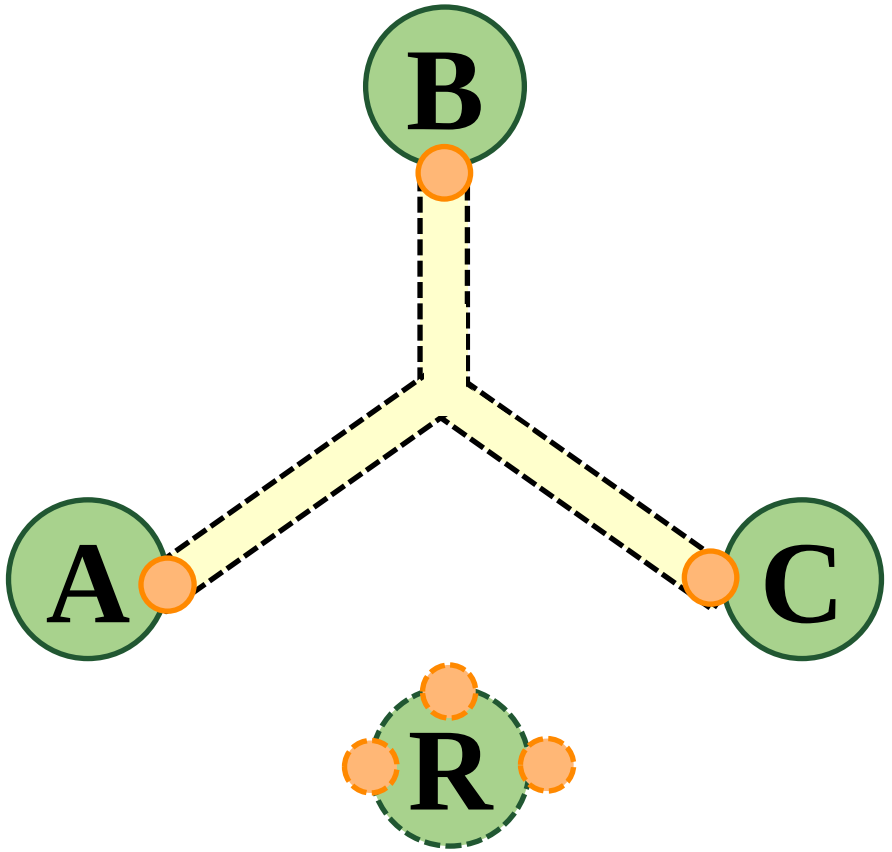
- **Shortest path**
- **Shortest k-Paths**: Redundant multiple paths for fault tolerance and purification
- **Multi-user**: Many different jobs on the QPUs ⇒ Need fair allocation
- **Multi-link**: Multiple entanglements per link
- **Multicast**: Entangle more than two bits
- Probabilistic and dynamic nature of entanglements makes several variations mentioned in the literature, such as static, proactive unrealistic.

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Multipartite States Implementation

- Introduced by Greenberger, Horne, Zeilinger (GHZ) for 3 or more qubits





- Allows **quantum multicasting**

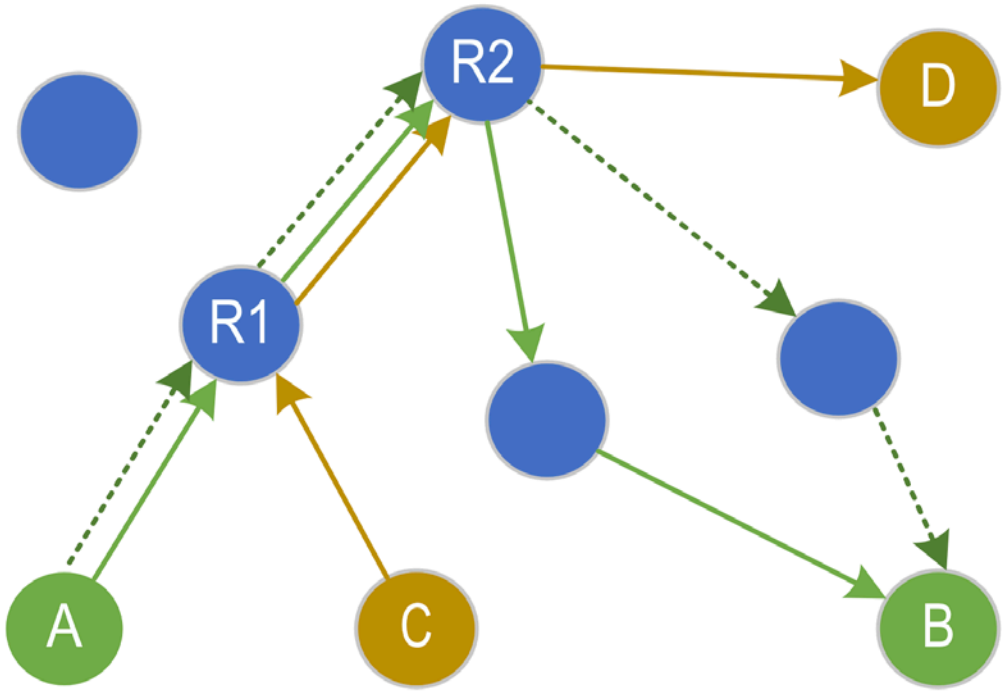
Refs: Chenliang Tian, Zebo Yang, Raj Jain, Ramana Kompella, Reza Nejabati, Eneet Kaur, Aiman Erbad, Mounir Hamdi, and Mohamed Abdallah, "Asynchronous Routing for Multipartite Entanglement in Quantum Networks," the 2026 IEEE 16th Annual Computing and Communication Workshop and Conference (CCWC), 5-7 January 2026, Las Vegas, NV, USA, http://www.cse.wustl.edu/~jain/papers/maer_ccwc.htm

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Machine Learning and Reinforcement Learning Approaches

- Reinforcement Learning (RL):
  - Agents learn routing policies via trial and error
  - Adapt to dynamic, uncertain network condition
- Deep RL (DRL):
  - Scales to large networks using neural networks
- Graph Neural Networks (GNNs):
  - Learn representations for scalable, topology-aware routing

Resource Management in Quantum Networks



Two paths found for Nodes A and B.
One path found for Nodes C and D.
All three paths need the link between R1 and R2.

- With multiple users, connection requests will arise concurrently, leading to a high demand for entanglement generation and swapping.
- Need to develop a fair resource scheduling algorithm for entanglement allocation
- We need to adapt the scheduling to the extremely fast and short-lived nature of entanglements

Ref: Zebo Yang, Chenliang Tian, Raj Jain, Ramana Kompella, Reza Nejabati, Mounir Hamdi, Aiman Erbad, Hassan Shapourian, "**Effective Scheduling for Quantum Data Centers**," Poster paper, 2025 IEEE International Conference on Quantum Computing and Engineering (QCE), August 2025, 2025, http://www.cse.wustl.edu/~jain/papers/qce25.htm

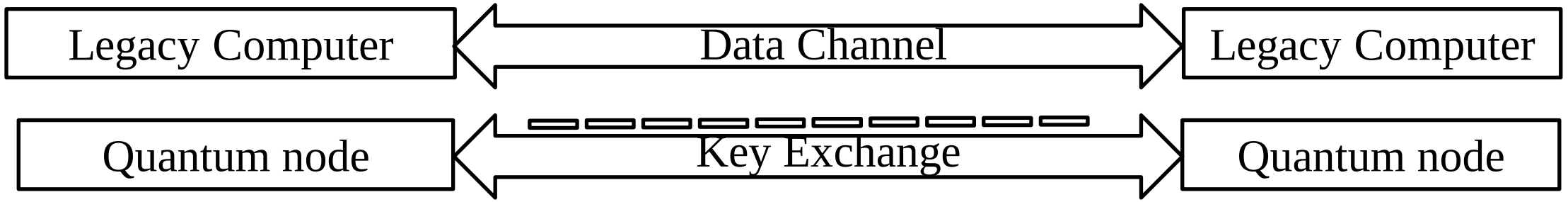
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Part 4: Standards Activities

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Quantum Key Distribution (QKD)

- Quantum computers are not yet suitable for very high-speed data transfer
- Quantum Link is a secure way to transfer encryption keys. While data goes on the traditional networks
- Many companies, such as Toshiba, ID Quantique, Quintessense Labs, MagiQ Technologies, QuantumCTek, etc., are making QKD equipment.
- These are being used in high-Security applications, such as Government, Defense, Banking, Financial services, Telecom providers, use these chips.



QKD is being used now for highly secure cryptographic key exchange

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Standards: ITU-T

- **QKD networks - Control and management**, ITU-T Y.3804 (04/2025)
- **Standardization Consideration of Satellite-Based QKDN**, ITU-T TR.SQKDN (03/2025)
- **Security requirements for the protection of QKD nodes**, ITU-T X.1713 (04/2024)
- **Integration of QKD network and user network supporting end-to end modern cryptography services – Requirements for QoS assurance**, ITU-T Y.3828 (04/2025)
- **QKD Networks– functional requirements and architecture for machine learning enablement**, ITU-T Y.3814 (01/2023)
- **QKD network interworking – Framework**, ITU-T Y.3810 (09/2024)
- **QKD networks use cases**, ITU-T Y Suppl. 80 (11/2023)
- **Standardization roadmap on QKD networks**, ITU-T Y Suppl. 74 (03/2023)

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Standards: ITU-T (Cont)

- **QKD networks – Applications of machine learning,** ITU-T Y Suppl. 70 (03/2021)
- **QKD Networks – Functional Architecture**, ITU-T Y.3802 (12/2020)
- **Functional requirements for QKD networks**, ITU-T Y.3801 (04/2020)
- **Overview on networks supporting QKD Corrigendum 1**, ITU-T Y.3800 Corrigendum 1 (04/2020)
- **Overview on networks supporting QKD**, ITU-T Y.3800 (10/2019)

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ETSI Standards

European Telecom Standards Institute (ETSI): New technical Committee TC QT (30 Sept. 25)

- **QKD Vocabulary**, ETSI GR QKD 007 V1.2.1 (2026-01)
- **QKD Common Criteria Protection Profile - Pair of Prepare and Measure Quantum Key Distribution Modules**, ETSI GS QKD 016 V2.1.1 (2024-01)
- **QKD Orchestration Interface for Software Defined Networks**, ETSI GS QKD 018 V1.1.1 (2022-04)
- **QKD Control Interface for Software Defined Networks**, ETSI GS QKD 015 V2.1.1 (2022-04)
- **QKD Application Interface**, ETSI GS QKD 004 V2.1.1 (2020-08)
- **QKD Protocol and data format of REST-based key delivery API**, ETSI GS QKD 014 V1.1.1 (2019-02)
- **QKD Device and Communication Channel Parameters for QKD Deployment**, ETSI GS QKD 012 V1.1.1 (2019-02)

Ref: https://www.etsi.org/committee/qkd

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Standards: IETF

- Internet Engineering Task Force is working mostly on Post-Quantum.
- Hybrid key exchange in TLS 1.3, draft-ietf-tls-hybrid-design-16, 11 March 2026, in RFC editor's queue
- PQ/T Hybrid Key Exchange with ML-KEM in SSH, draft-ietf-sshm-mlkem-hybrid-kex-10, 3 March 2026, in RFC Editor's queue, Informational RFC
- Post-quantum Hybrid Key Exchange in the IKEv2 with FrodoKEM, draft-wang-ipsecme-hybrid-kem-ikev2-frodo-00, 4 Sep 2025. The word Frodo comes from Frodo Baggins from the Lord of the Rings. This emphasizes that this a simple, conservative, no-magic-rings approach.

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Standards: GSMA

- **GSM Association (GSMA):**
  - **Quantum Networking and Service,** Version 1.0, December 2021
  - **Quantum Computing Networking and Security**, Version 1.0, March 2021.

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Part 5: Challenges and Myths

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Quantum Computing Challenges

1. Quantum devices are noisy and probabilistic.
2. Error correction requires many *physical* qubits to produce each error-corrected *logical* qubit required for algorithms (e.g., Shor)
   - QuantWare VIO-40K claimed 10,000 qubits in December 2025.
   - QuEra achieved 30 logical qubits with 3,000 physical qubits in 2025.
3. There are many different qubit technologies, each with its own advantages and limitations. Without convergence, research efforts are fragmented.
4. More qubits in a single QPU result in higher noise and error rates. One solution is to use distributed quantum computing via networks of smaller QPUs. IBM recently signed a contract with Cisco for quantum networking.

Ref: R. Deffenbaugh, "IBM, Cisco Partner On Quantum Computing. IBM Stock Gains Despite Retreat For AI Stock Rally," Investor's Business Daily, Nov. 20, 2025, https://www.investors.com/news/technology/ibm-cisco-team-up-for-quantum-computing-network-plan-ibm-stock-gains-above-key-level/

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Common Myths about Quantum

1. **Superposition allows quantum particles to be in two places at once.** The particle is in a state that has multiple possibilities, and only measurement yields a definite outcome. Probabilistic ≠ Multiple.
2. **Entanglement allows communication faster than the speed of light**: While the remote states are correlated, the receiver cannot make any sense of the state until it receives the measurement basis via classical channels.
3. **Quantum mechanics is only about tiny particles**. Superconductors, lasers, and MRI are examples of macroscopic quantum effects. These can not be explained by classical physics, only by quantum mechanics.

Ref: Zebo Yang, Ali Ghubaish, Raj Jain, Ala Al-Fuquha, Aiman Erbad, Ramana Compella, Hassan Shapourian, Reza Nejabati, "**Layer-Wise Security Framework and Analysis for the Quantum Internet**," IEEE Selected Areas in Communications, Vol. 43, Issue 8, pp. 2825-2840, Aug. 2025, http://www.cse.wustl.edu/~jain/papers/quint.htm

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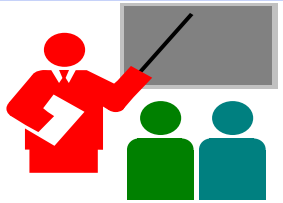
Quantum Network Security

4. Quantum is secure: While quantum can break current security, it is itself susceptible to quantum attacks (see our paper below).

- Quantum communication is assumed to be very secure because reading information on the way destroys the information
  $\Rightarrow$ Any attack is immediately detected
- We have identified several attacks that can affect quantum communication in physical, network, and application layers
- Also suggested mitigation strategies and analyzed their effectiveness

Ref: Zebo Yang, Ali Ghubaish, Raj Jain, Ala Al-Fuquha, Aiman Erbad, Ramana Compella, Hassan Shapourian, Raza Nejabati, "**Layer-Wise Security Framework and Analysis for the Quantum Internet**," IEEE Selected Areas in Communications, 2025, http://www.cse.wustl.edu/~jain/papers/quint.htm

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Summary

1. It is best to learn/research/work in a field at the left of its hype cycle peak
   $\Rightarrow$ This is a prime time for computer scientists to get in.
2. Quantum computing is here. IBM, Microsoft, and Google all have invested in quantum computing. Numerous companies are producing quantum-related products and using quantum techniques.
3. While much work has been done on the physics of quantum, system-level issues are equally important for Quantum to succeed. Quantum networking, resource management, quantum error correction, and security are all hot.
4. Standardization efforts have been focusing on QKD. But networking at the cluster, data center, inter-data center, and Internet levels presents significant research opportunities.

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Our Publications on Quantum

- Chenliang Tian, Zebo Yang, Raj Jain, Ramana Kompella, Reza Nejabati, Eneet Kaur, Aiman Erbad, Mohamed Abdallah and Munir Hamdi, "**RADAR-Q: Resource-Aware Distributed Asynchronous Routing for Entanglement Distribution in Multi-Tenant Quantum Networks**," Fifth International Conference on Innovations in Computing Research (ICR'26), Berlin, Germany, August 24-26, 2026, http://www.cse.wustl.edu/~jain/papers/radar_q.htm
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- Zebo Yang, Tara Salman, Raj Jain, and Roberto Di Pietro, "**Decentralization using Quantum Blockchain: A Theoretical Analysis**," IEEE Transactions on Quantum Engineering, September 2022, 16 pp., http://www.cse.wustl.edu/~jain/qbif.htm
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Acronyms

- AER Asynchronous Entanglement Routing
- AFRL Air Force Research Lab
- AI Artificial Intelligence
- APAC Asia-Pacific
- API Application Programming Interface
- ARL Army Research Lab
- ARPA Advanced Research Project Agency
- CAS Chinese Academy of Sciences
- CCWC Computing and Communication Workshop and Conference
- CRYSTALS Cryptographic Suite for ALgebraic Lattices
- DC District of Columbia
- DOD Department of Defense
- DODAG Destination Oriented Directional Acyclic Graph
- DOE Department of Energy
- DRL Defense Research Lab
- DSA Digital Signature Algorithm

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Acronyms (Cont)

- ECC Elliptic Curve Cryptography
- ESNet Energy Science Network
- ETSI European Telecommunications Standards Institute
- EU European Union
- FALCON Fast-Fourier Lattice-based Compact Signature over NTRU
- FIPS Federal Information Processing Standard
- FN FFT over NTRU Lattice based
- FT Fourier Transform
- FrodoKEM Frodo Key Encapsulation Mechanism
- GNN Graph Neural Networks
- GSM Global Standards for Mobiles
- GSMA GSM Association
- HSM Hardware Security Modules
- IARPA Intelligence Advanced Research Project Agency
- IBM International Business Machines
- ICR Innovation in Computing Research

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Acronyms (Cont)

- ID Information and Data (in ID Quantum)
- ID Identifier
- IEEE Institution of Electrical and Electronics Engineers
- IETF Internet Engineering Task Force
- IKEv2 Internet Key Exchange version 2
- ITU International Telecommunications Union
- ISBN International Standard Book Number
- KEM Key Encapsulation Mechanism
- LOUD A surface level facility similar to but opposite of QUIET
- MagiQ Not an acronym. Just a part of a name MagiQ Technologies
- MIT Massachusetts Institute of Technology
- mK Milli-Kelvin
- ML Machine Learning
- MO Missouri
- MRI Magnetic Resonace Imaging
- NASA National Aeronautics and Space Administration

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Acronyms (Cont)

- NISQ Noisy Intermediate-Scale Quantum
- NIST National Institute of Standards and Technology
- NQCO National Quantum Coordination Office
- NQN National Quantum Nanofab
- NRDC National Development Reform Council
- NRL Navy Research Lab
- NSA National Security Agency
- NSF National Science Foundation
- NTRU Number Theory Research Unit
- OpenQASM Qiskit Open Quantum Assembly Language
- PQ Post-Quantum
- QAOA Quantum approximate optimization algorithm
- QC Quantum Computing
- QCE Quantum Computing and Engineering
- QCEngine Quantum Computing Engine
- QExperience Quantum Experience

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Acronyms (Cont)

- QFP Quantum Forward Plane
- QFT Quantum Fourier Transform
- QinetiQ A security and defense contractor
- QISKit IBM's quantum simulation package
- QKD Quantum Key Distribution
- QKDN Quantum Key Distribution Network
- QML Quantum Machine Learning
- QPU Quantum Processing Unit
- QoS Quality of Service
- QSVM Quantum Support Vector Machine
- QuByte Quantum Byte
- QuEra QuEra company
- QUIET Quantum Underground Instrumentation Experimental Testbed
- RADAR-Q resource-aware distributed asynchronous routing protocol for Quantum
- REST Representational State Transfer
- RFC Request for Comments

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Acronyms (Cont)

- RL — Reinforcement Learning
- RSA — Rivest, Shamir, Adleman
- SDN — Software Defined Networking
- SLH-DSA — Stateless Digital Signature Algorithm
- SPHINCS — Practical stateless Hash-based Signature
- SQKDN — Satellite Quantum Key Distribution Network
- SSH — Secure Shell
- SURFNet — Samenwerkende Universitaire Rekenfaciliteiten (Cooperating University Computing) Facilities
- TC — Technical Committee
- TLS — Transport Level Security
- TPM — Trusted Platform Module
- TR — Technical Report
- UK — United Kingdom
- US — United States

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Acronyms (Cont)

- USA United States of America
- USNO United States Naval Observatory
- USTC University of Science and Technology of China
- VQE Variational Quantum Eigensolver
- WashU Washington University
- WUSTL Washington University in Saint Louis
- XOR Exclusive OR gate

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