# Quantum Networking: Challenges and Research Opportunities



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These slides are available at: http://www.cse.wustl.edu/~jain/talks/qnt_ccwc.htm


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# Overview

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


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# Part 1: Why Quantum?


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# Selecting the Right Research Topic/Field

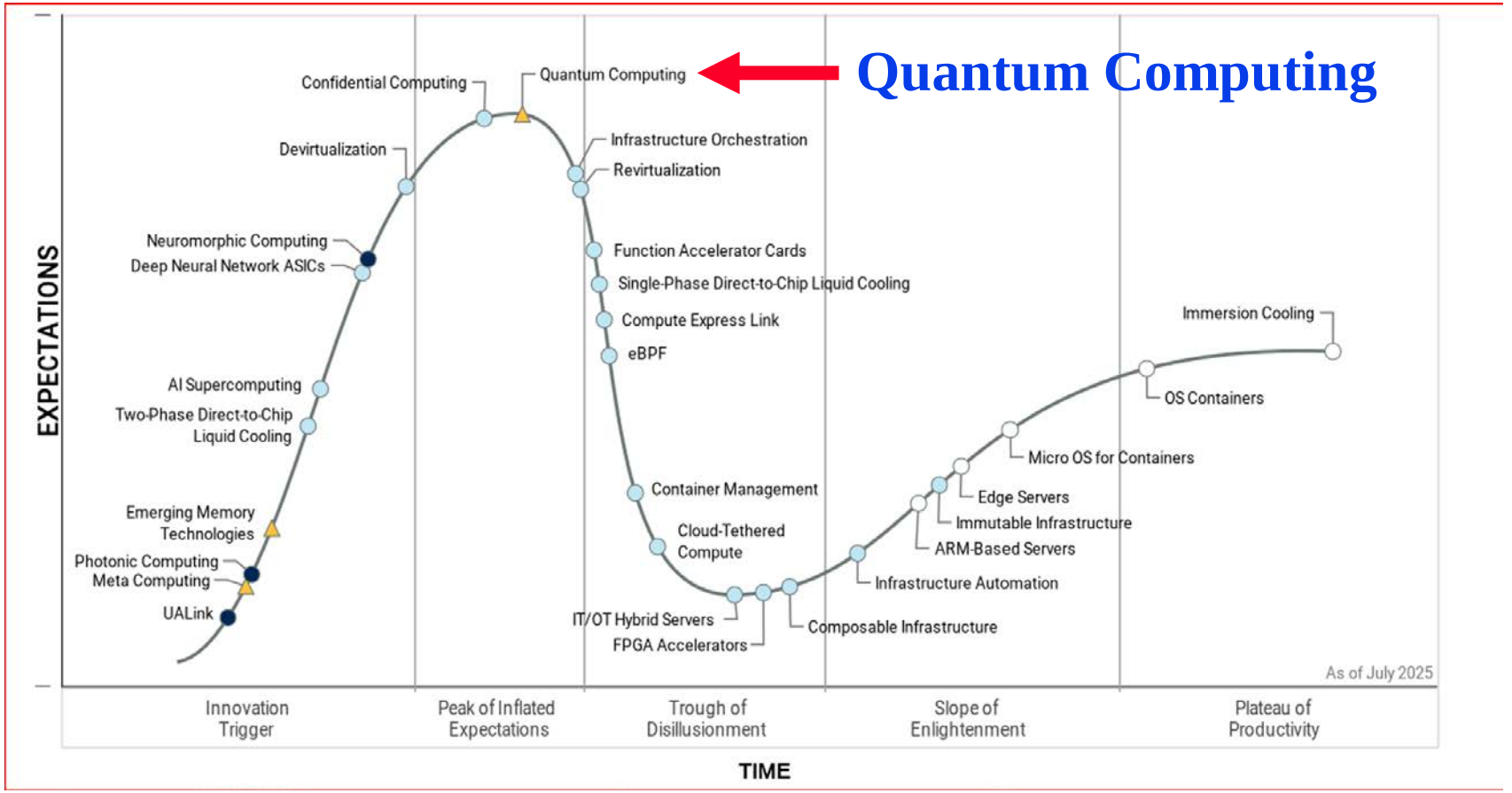
- An important question for students, academics, entrepreneurs, and companies
- Most academics follow the herd or stick to their old expertise.
- Goal: To impact ⇒ Follow the **paradigm shifts**:
  - 2008: Next Generation Internet/SDN
  - …
  - 2025: Whatever is being **hyped** this year?
- The United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



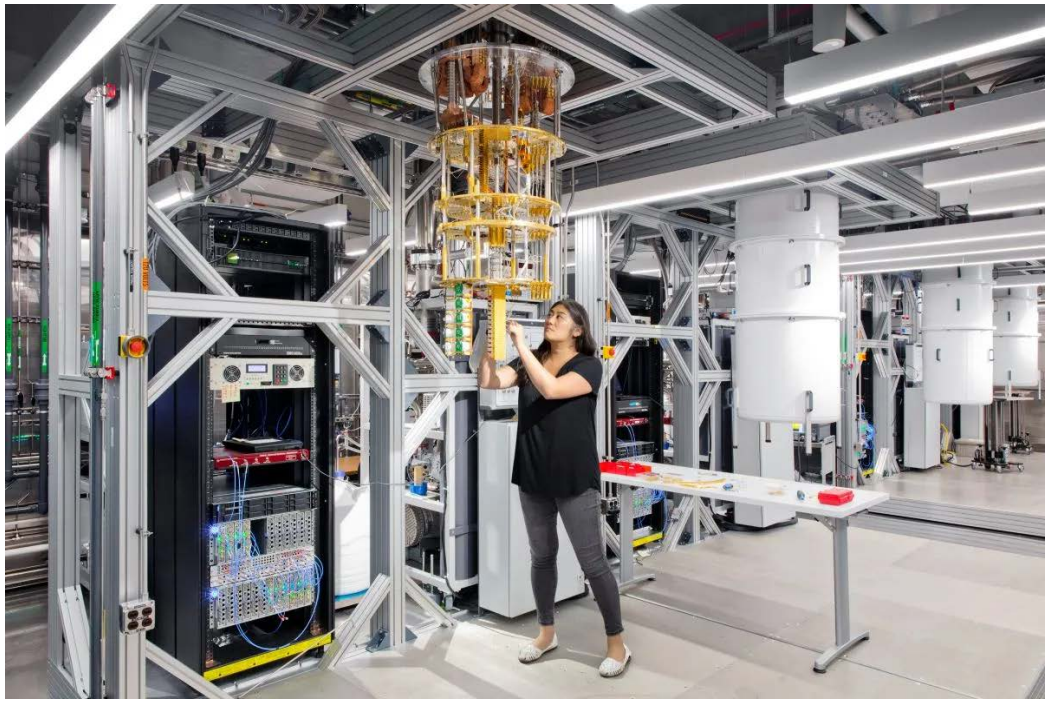

**This is the right time to get into Quantum.**

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

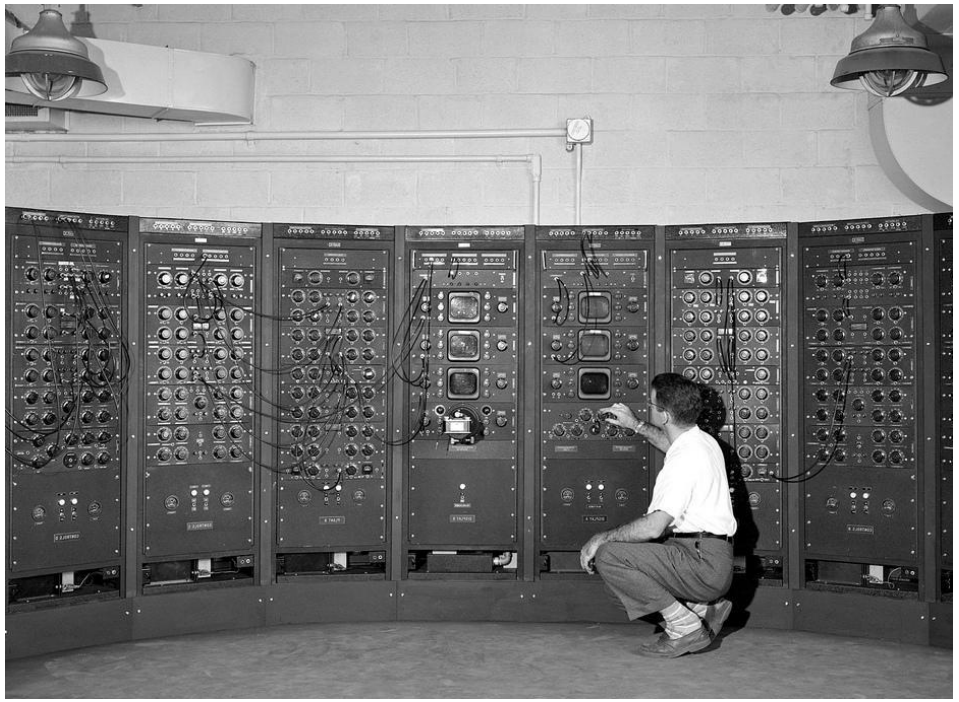


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# Dawn of Quantum Computing



IBM's Quantum computer



ENIAC (1943)

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 FALCAN (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

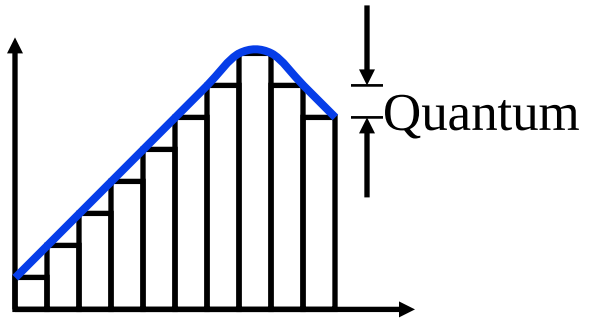

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# Part 2: What is Quantum?


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# What is a Quantum?

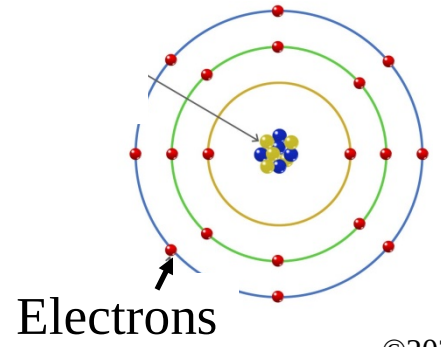
- Quantization: Analog to digital conversion
- Quantum = Smallest discrete unit
- **Wave Theory**: Light is a wave. It has a frequency, phase, and amplitude
- **Quantum Mechanics**: Light behaves like discrete packets of energy that can be absorbed and released
- **Photon** = One quantum of light energy
- 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









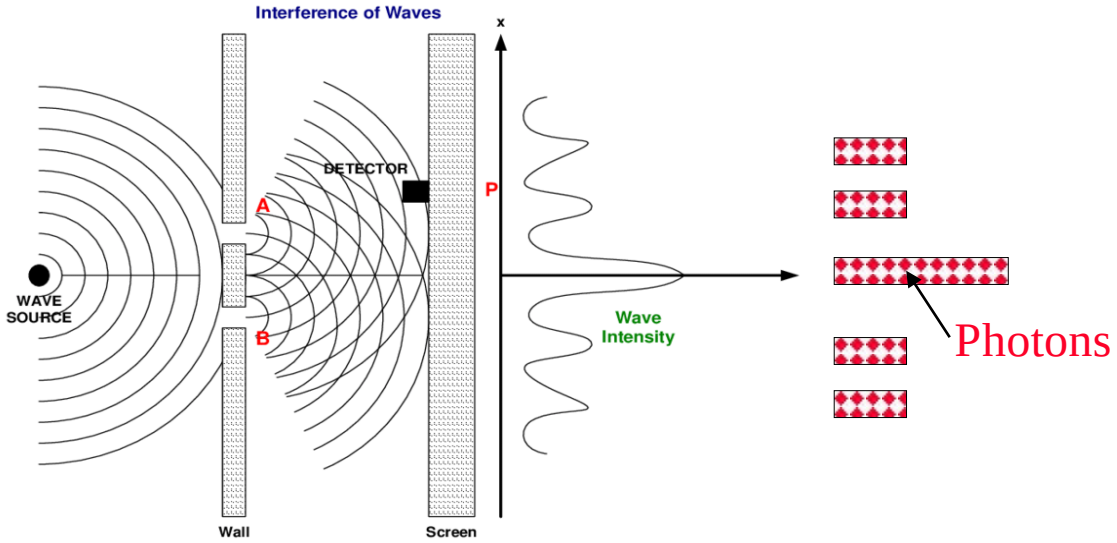





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# Are Photons Particles or a Wave?

- 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

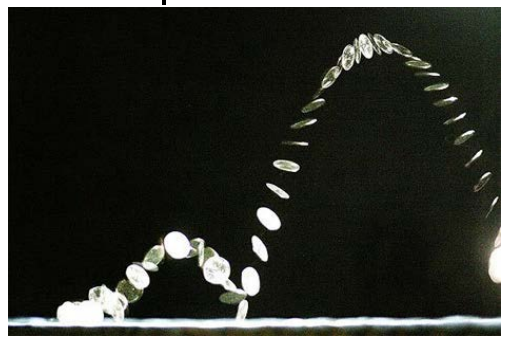
- Qubits are probabilistic. The elements of the vector indicate the probability amplitude.

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

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

- 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

- One important property of quantum bits (qubits) is that if you measure it, it is destroyed
- 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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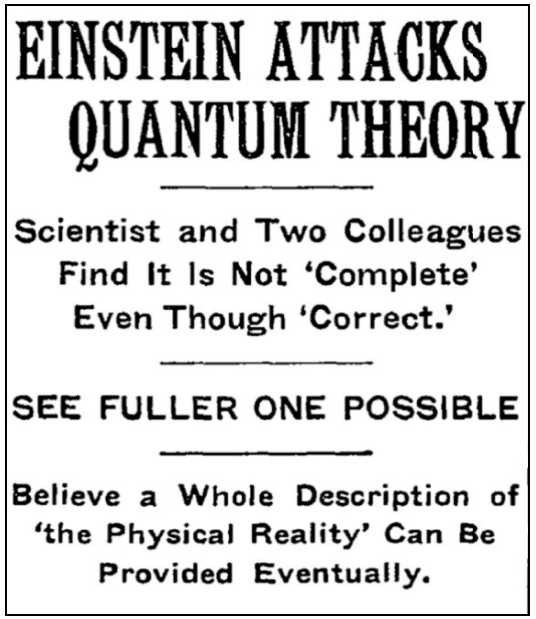


# Entanglement



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 happen at a speed faster than light
- 1967: Kocher invented an apparatus for entangled photons
- 2022: Physics Nobel Prize for experiments with entangled photons



EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.

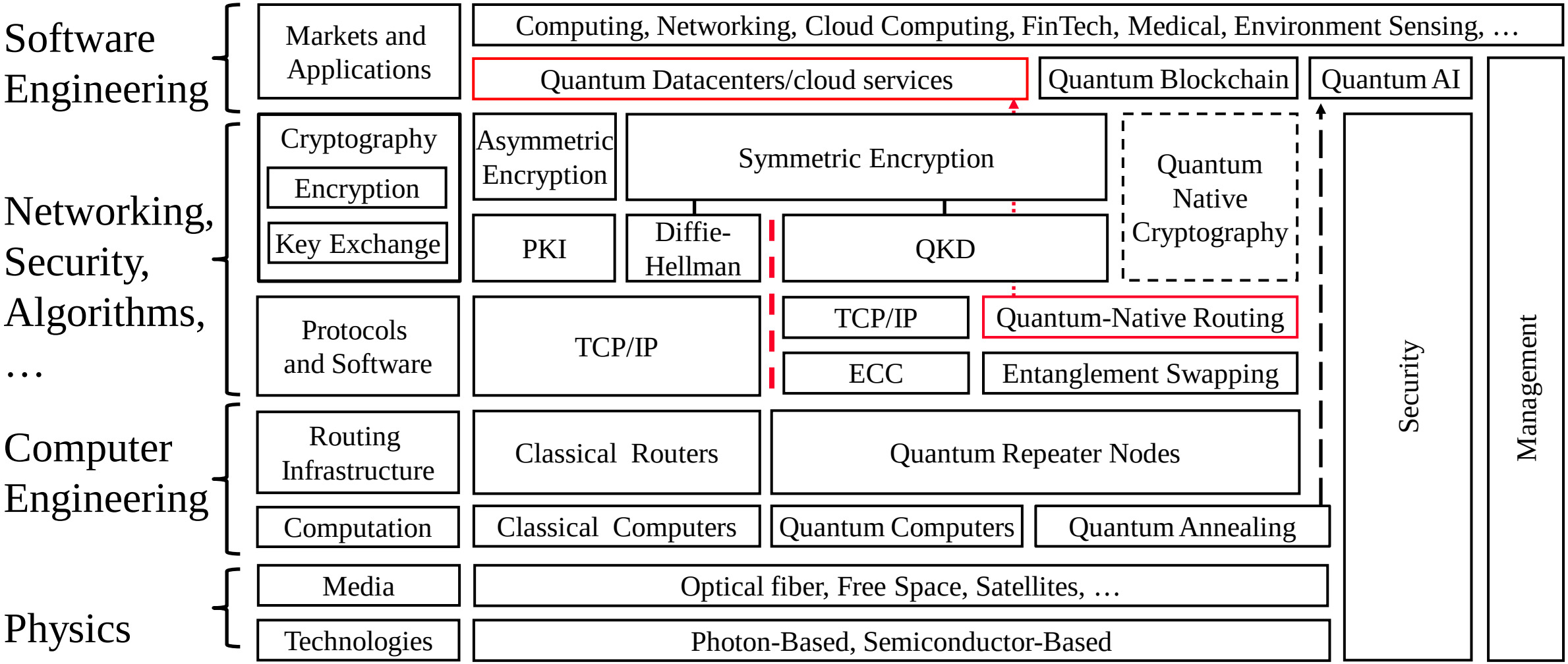
May 4, 1935 Issue of the New York Times, Source: Wikipedia

**Entanglement allows communication via qubits.**


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# Part 3: How to do Quantum Networking?

# 7-Layers Stack of Quantum Research




**Quantum research is dominated by the physics department.**



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# Challenges in Quantum-Native Networking

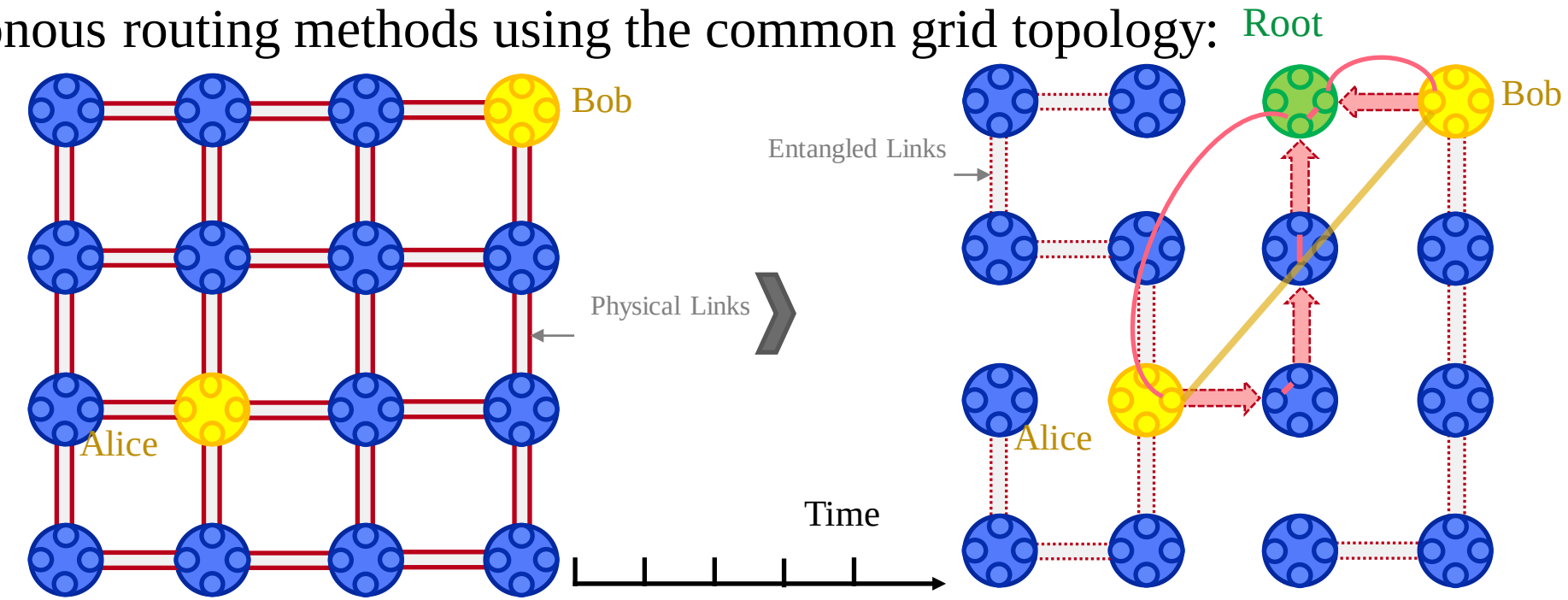
1. Entanglement of a link is destroyed once the data is transmitted.
   ⇒ Need to reestablish remote entanglement for each use.
2. Qubit is lost at the sender due to measurement.
3. De-coherence: Qubits are lost quickly (ranging from μs to s).
   ⇒ Entanglement can decohere.
   ⇒ The transmission must 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.

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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# Our Vision

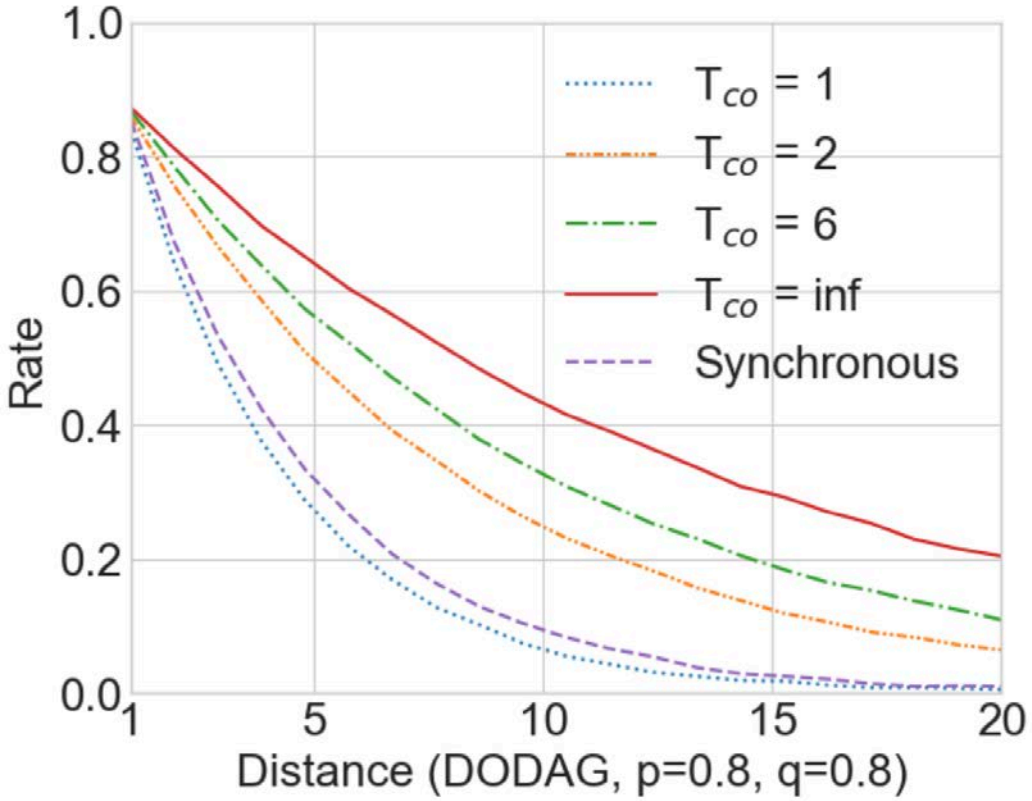
- We proposed an Asynchronous Entanglement Routing (**AER**) scheme using DODAG or a spanning tree, similar to those used in the Internet of Things and Ethernet.
- We completed the design, analysis, and simulation. Compared our results with the existing synchronous routing methods using the common grid topology:

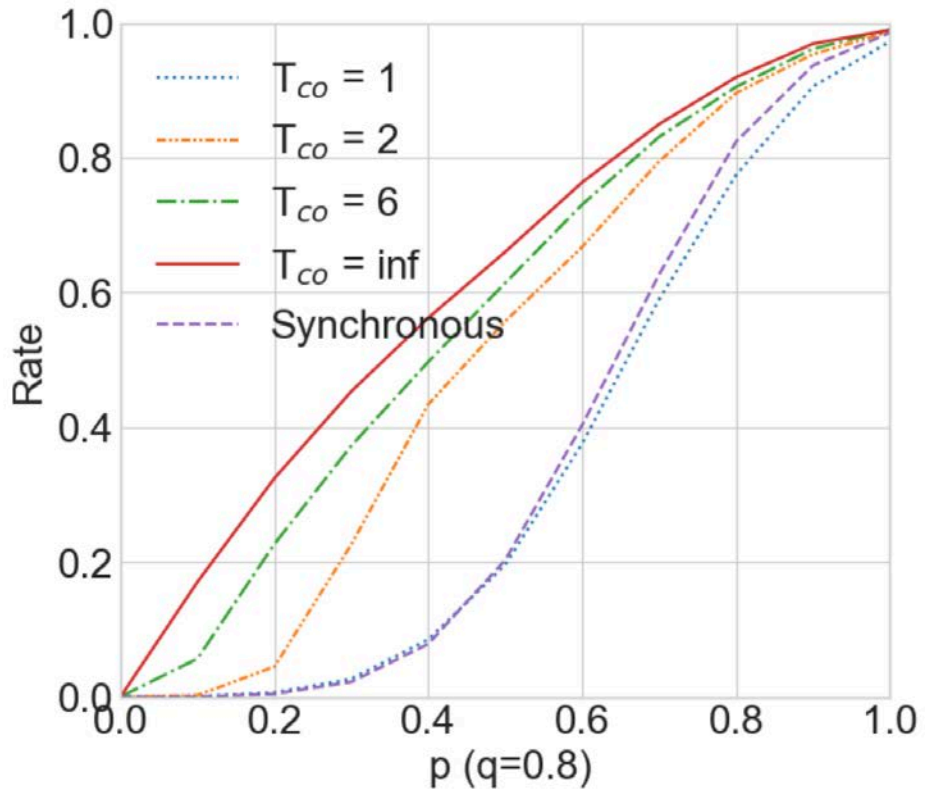



Ref: Zebo Yang, Ali Ghubaish, Raj Jain, and H. Shapourian, "**Asynchronous Entanglement Routing for the Quantum Internet**," AVS Quantum Sci. 6, 013801, Jan 2024, http://www.cse.wustl.edu/~jain/papers/qrout.htm


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# AER Analysis and Simulation



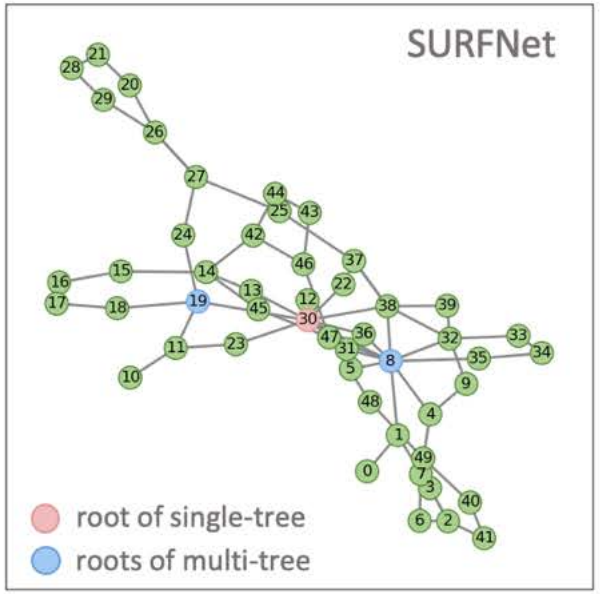

**p:** direct-link entanglement generation success rate; **q:** entanglement swapping success rate; **$T_{co}$:** coherence time

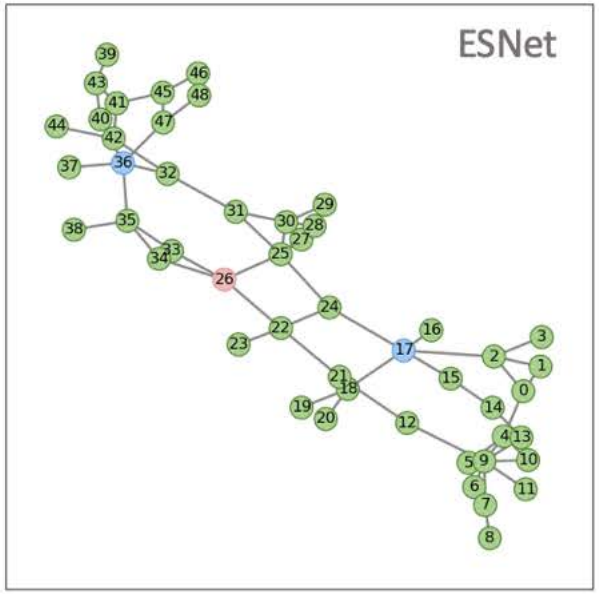
The end-to-end entanglement rate of asynchronous routing increases with the coherence time, decays slower, and is generally larger than synchronous approaches.

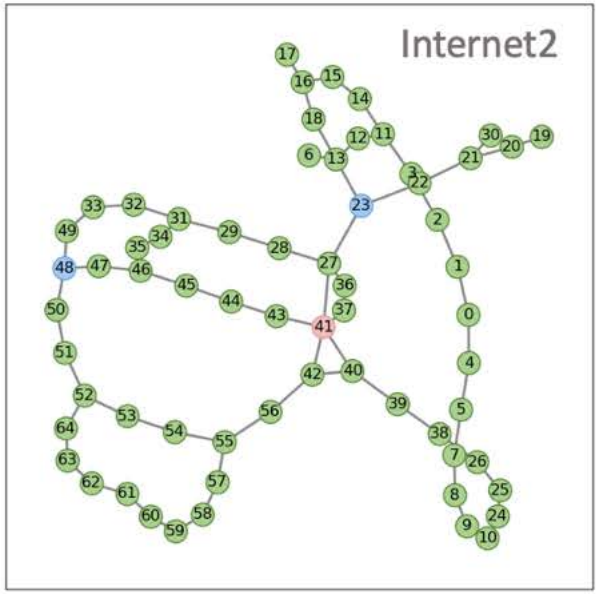


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# Realistic Topology Experiments




- The three topologies have different structures:

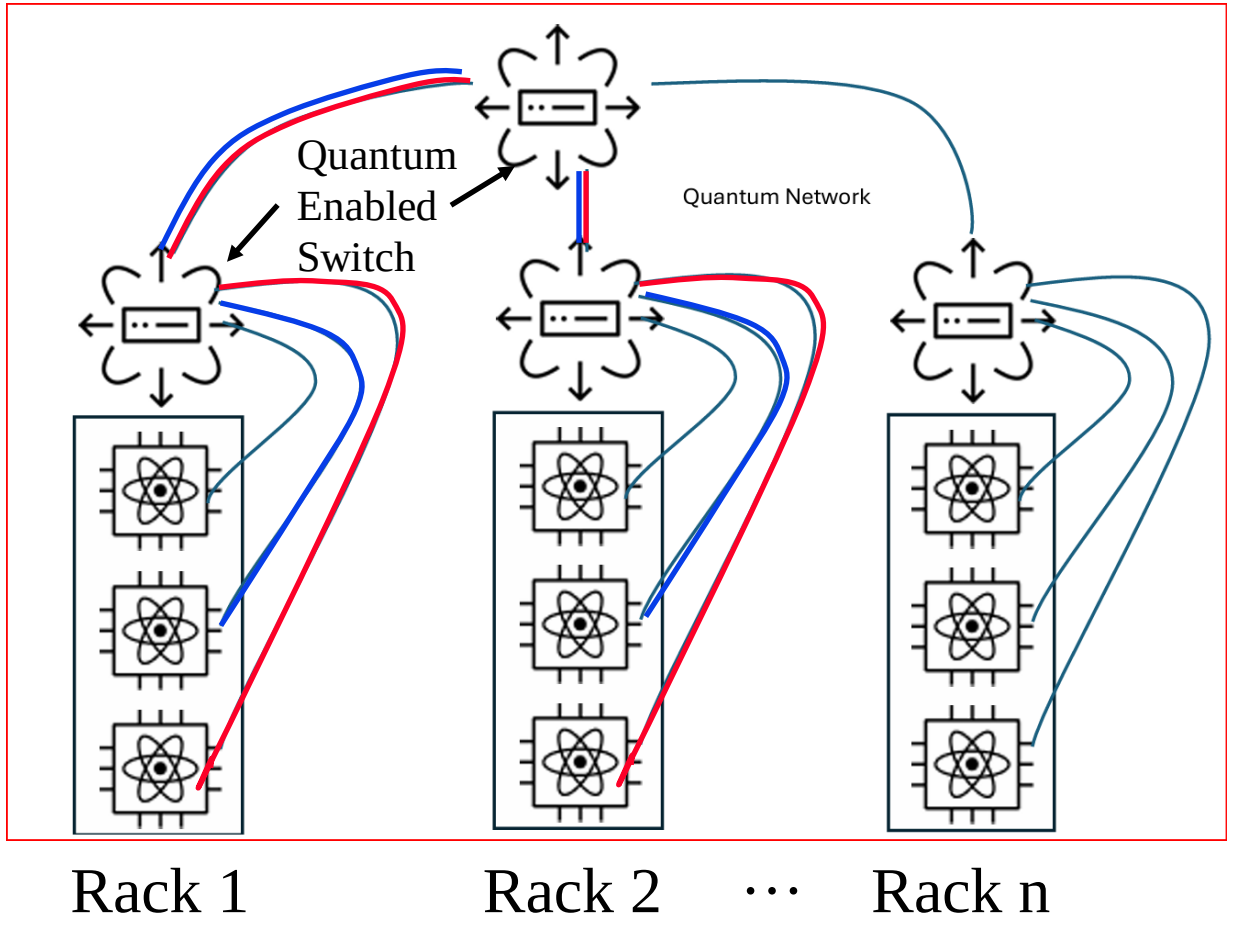
1. SURFNet has nodes with strong connections, making them suitable candidates for root nodes.
2. ESNet exhibits less densely distributed nodes and fewer highly connected central nodes
3. Internet2 includes long linear chains in its topology.

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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# Resource Management 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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# Part 4: Quantum Applications


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# Quantum Supremacy

- **Quantum Supremacy**: Solve a problem on a quantum computer that can not be solved on a classical computer
- Google announced it had achieved Quantum Supremacy on October 23, 2019. It's Sycamore processor completed a random-circuit sampling task in 200 seconds, which they estimated would take a classical computer 10,000 years. ⇒ Debate about whether this is useful or meaningful.
- QPU Makers: IBM, Microsoft, Google, Alibaba Cloud, D-Wave Systems, 1QBit, QC Ware, QinetiQ, Rigetti Computing, Zapata Computing, …
- Global Competition: China, Japan, USA, EU are also competing

Ref: F. Arute, K. Arya, R. Babbush, *et al.*, "Quantum supremacy using a programmable superconducting processor," *Nature* **574,** 505–510 (Oct. 23, 2019), https://www.nature.com/articles/s41586-019-1666-5


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# Shor's Factoring Algorithm

- Fourier Transform can be used to find periodic components of signals.
- Digital Fourier Transform (DFT) has exponential complexity.
- Quantum Fourier Transform can be implemented with $n^2$ complexity
- Peter Shor used QFT and showed that Quantum Computers can find prime factors of large numbers exponentially faster than conventional computers.
  $\Rightarrow$ This lead to the race for quantum computing.
- Need a large number of qubits to break RSA.


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# Quantum Random Number Generator

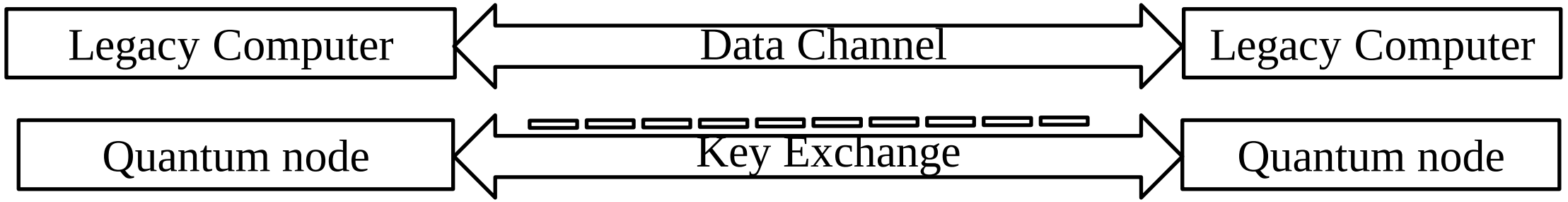
- Cryptographic keys generated using pseudo-random number generators (PRNG) can be broken using the known information about the PRNG.
- It is easy to get true random numbers using quantum mechanics
- Several companies supply QRNT chips, e.g., ID Quantique (IDQ), InfiniQuant, KETS Quantum Security, Nu Quantum, PicoQuant, Qrypt, Quandela, QuintessenceLabs, S Fifteen Instruments, ThinkQuantum, Sequre Quantum, TectroLabs, Light Rider, ComScire, Alea Quantum Technologies
- High-Security applications, such as Government, Defense, Banking, Financial services, Telecom providers, use these chips.
- Samsung uses a QRNG chip in Galaxy Quantum 2 smartphones

Ref: E. Gent, "Quantum Randomness Now Boosts Everyday Security," IEEE Spectrum, Aug 2021, https://spectrum.ieee.org/quantum-randomness-boosts-everyday-security


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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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# Quantum Machine Learning (QML)

- Quantum for solving systems of linear equation
- Quantum Principal Component Analysis
- Quantum Support Vector Machines (QSVM)
  - Classical SVM has runtime of O(poly($m$,$n$)), $m$ data points, $n$ features
  - QSVM has runtime of O(log($mn$))
    - Currently limited to data that can be represented with small number of qubits
- QML can process data directly from Quantum sensors with full range of quantum information

Ref: E. R. Johnston, N. Harrigan, and M. Gimeno-Segovia, "Programming Quantum Computers," O'reilly, 2019, ISBN:9781492039686, 320 pp.


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# Quantum Computing Applications

- **Optimization (Scheduling, Networking):** Logistics companies and Telcos are running quantum-assisted optimizers to reduce routing, scheduling, and resource-applications costs in real-time.
- **Approximate Optimization:**
  - Quantum approximate optimization algorithm (QAOA) using hybrid quantum-classical algorithms
  - Variational Quantum Eigen Solver (VQE) using hybrid quantum-classical algorithms. Used in quantum chemistry and material science since it is robust against noise. Ideal for the current **Noisy Intermediate-Scale Quantum** (**NISQ**).


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# Quantum Computing Applications (Cont)

- **Simulations for Autonomous Vehicle Testing**: Accelerated roading by simulating millions of scenarios related to weather, traffic, and terrain to test and validate.
- **Drug Discovery and Healthcare**: Simulating molecules to design new medicines
- **Materials Design and Chemistry**: Quantum simulations target catalysts, battery materials, and superconductors.
- **Finance**: Risk, portfolio optimization, derivative pricing with quantum optimizations
- **Artificial Intelligence**: Enhancing AI with hybrid quantum-classical models.


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# Quantum Computing Applications (Cont)

- **Cyberecurity**: Breaking traditional encryption and also developing quantum-proof security. Quantum key distribution.
- **Quantum Sensing**: Quantum sensors (atomic clocks, magnetometers, gravimeters) for navigation, geology, and fundamental physics experiments.
- **Climate Modeling**: Ultra-precise simulations of Earth's Climate
- **Space Research**: Helping Astrophysicists simulate dark matter, black holes, and cosmic events.

Ref: Forbes, "20 Real-world Applications of Quantum Computing to Watch," June 9, 2025, https://www.forbes.com/councils/forbestechcouncil/2025/06/09/20-real-world-applications-of-quantum-computing-to-watch/


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# Part 4: 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/

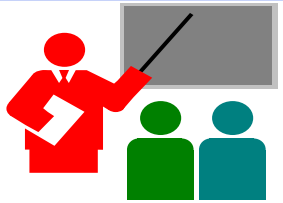

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# Common Myths about Quantum

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

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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# Summary

1. It is best to learn/research/work in a field at its left of its peak ⇒ This is a prime time for computer scientists to get in. Quantum networking, resource management, quantum error correction, and security are just a few topics.
2. A qubit is a two-element vector. Each element is a complex number that indicates the probability amplitude of that level. $n$-qubits have $2^n$ elements.
3. Shor's factorization algorithm is an example of an algorithm that can be done in exponentially faster time than in classical computing.
4. 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.
5. Quantum-Safe Crypto has been standardized.
6. Quantum is already being used in numerous applications.


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# Our Publications on Quantum

- Chenliang Tian, Zebo Yang, Raj Jain, Ramana Kompella, Reza Nejabati, Eneet Kaur, Aiman Erbad, Munir Hamd[5], and Mohamed Abdalla, "Asynchronous Routing for Multipartite Entanglement in Quantum Networks," 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_ccwc26.htm
- 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
- 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
- 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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# Our Publications on Quantum (Cont)

- Zebo Yang, Haneen Alfauri, Behrooz Farkiani, Raj Jain, Roberto DiPietro, and Aiman Erbad, "A Survey and Comparison of Post-quantum and Quantum Blockchains," IEEE Communications Surveys & Tutorials, 2nd Quarter 2024, Vol. 26, Issue 2, http://www.cse.wustl.edu/~jain/papers/qbpqb.htm
- Zebo Yang, Maede Zolanvari, Raj Jain, "A Survey of Important Issues in Quantum Computing and Communications," IEEE Communications Surveys and Tutorials, March 2023, http://www.cse.wustl.edu/~jain/papers/qsurvey.htm
- 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
- Zebo Yang, "Scaling Quantum Systems: Quantum Networks, Distributed Quantum Computing, and Security," Ph.D. Thesis, Washington University, May 2025, http://www.cse.wustl.edu/~jain/theses/zebophd.htm


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# Acronyms

- AER Asynchronous Entanglement Routing
- AFRL Air Force Research Lab
- AI Artificial Intelligence
- APAC Asia-Pacific
- APS American Physical Society
- ARL Army Research Lab
- ARPA Advanced Research Project Agency
- CAS Chinese Academy of Sciences
- CMOS Complementary Metal-Oxide Semiconductor
- CRYSTALS Cryptographic Suite for ALgebraic Lattices
- DC District of Columbia
- DOD Department of Defense
- DODAG Destination Oriented Directional Acyclic Graph


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# Acronyms (Cont)

- DOE Department of Energy
- DSA Digital Signature Algorithm
- ECC Elliptic Curve Cryptography
- ESNet Energy Science Network
- EU European Union
- FALCON Fast-Fourier Lattice-based Compact Signature over NTRU
- FIPS Federal Information Processing Standard
- FT Fourier Transform
- HSM Hardware Security Modules
- IARPA Intelligence Advanced Research Project Agency
- IBM International Business Machines
- IEEE Institution of Electrical and Electronics Engineers
- ISBN International Standard Book Number
- KEM Key Encapsulation Mechanism
- MIT Massachusetts Institute of Technology


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# Acronyms (Cont)

- mK Milli-Kelvin
- ML Machine Learning
- MO Missouri
- NASA National Aeronautics and Space Administration
- 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
- NSA National Security Agency
- NSF National Science Foundation
- NTRU Number Theory Research Unit
- OpenQASM Qiskit Open Quantum Assembly Language


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# Acronyms (Cont)

| | |
|---|---|
| PA | Pennsylvania |
| QAOA | Quantum approximate optimization algorithm |
| QC | Quantum Computing |
| QCEngine | Quantum Computing Engine |
| QExperience | Quantum Experience |
| QFT | Quantum Fourier Transform |
| QinetiQ | A security and defense contractor |
| QISKit | IBM's quantum simulation package |
| QKD | Quantum Key Distribution |
| QML | Quantum Machine Learning |
| QPU | Quantum Processing Unit |
| QSVM | Quantum Support Vector Machine |
| QuByte | Quantum Byte |
| QuEra | QuEra company |
| QUIET | A place to study quantum shielded from the effects of noise |
| RSA | Rivest, Shamir, Adleman |


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# Acronyms (Cont)

- SDN — Software Defined Networking
- SLH-DSA — Stateless Digital Signature Algorithm
- SPHINCS — Practical stateless Hash-based Signature
- SURFNet — Samenwerkende Universitaire Rekenfaciliteiten (Cooperating University Computing) Facilities
- SVM — Support Vector Machine
- TPM — Trusted Platform Module
- UK — United Kingdom
- US — United States
- 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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