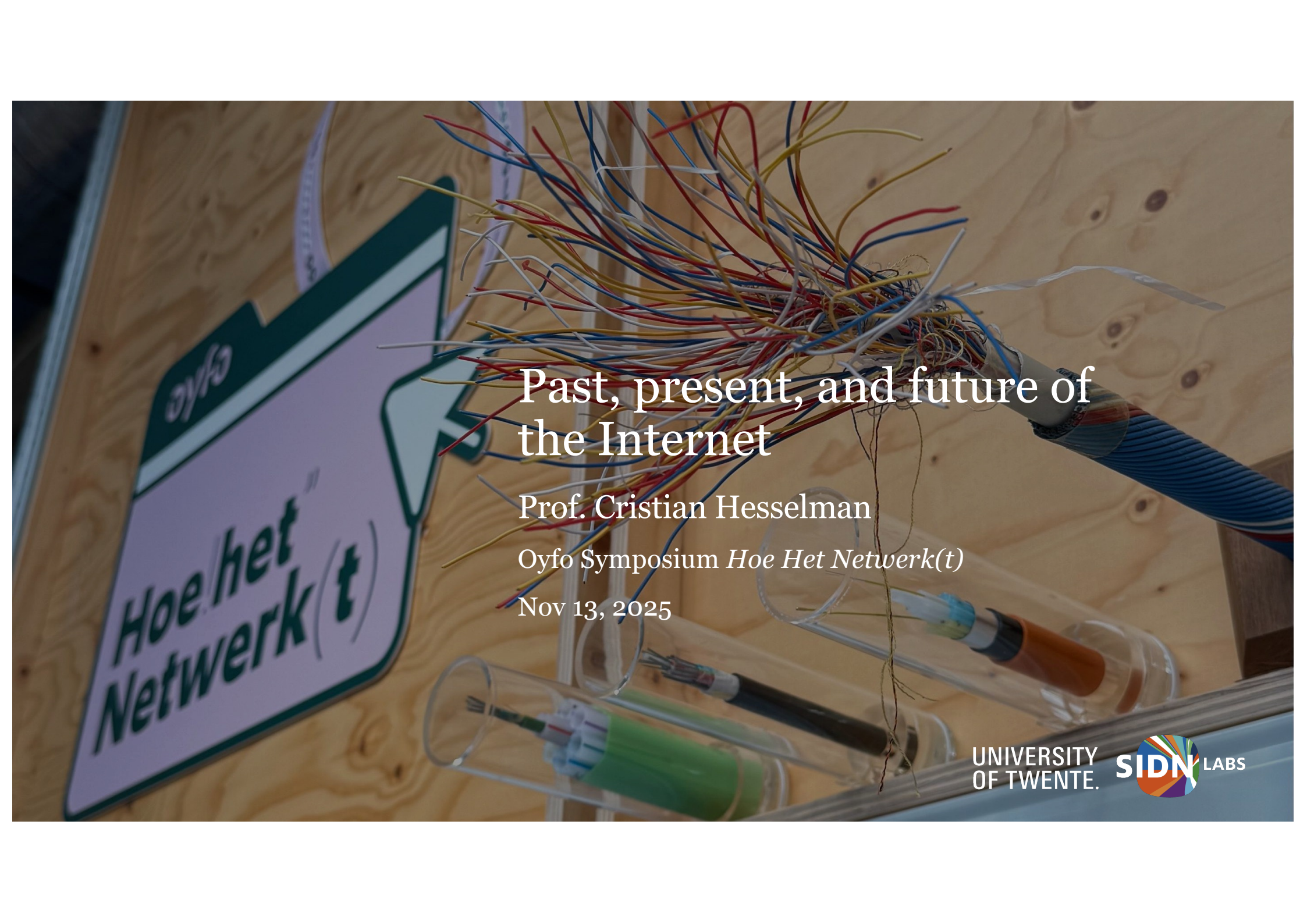




Past, present, and future of the Internet

Prof. Cristian Hesselman

Oyfo Symposium *Hoe Het Network(t)*

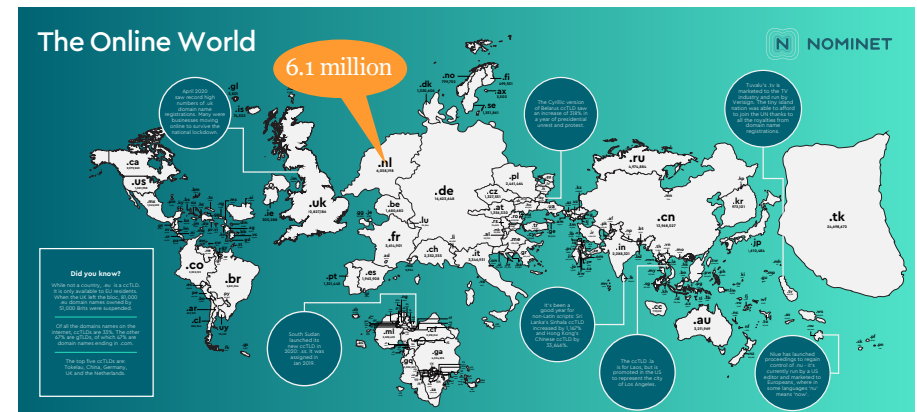
Nov 13, 2025

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About me

- I'm with SIDN, the operator of the Netherlands' Internet domain, .nl
- Director of SIDN Labs, SIDN's research team
- Professor of Trusted Open Networking at the University of Twente
- Member of the Netherlands' Cyber Security Council



<https://www.nominet.uk/delving-into-the-digital-world-map/>

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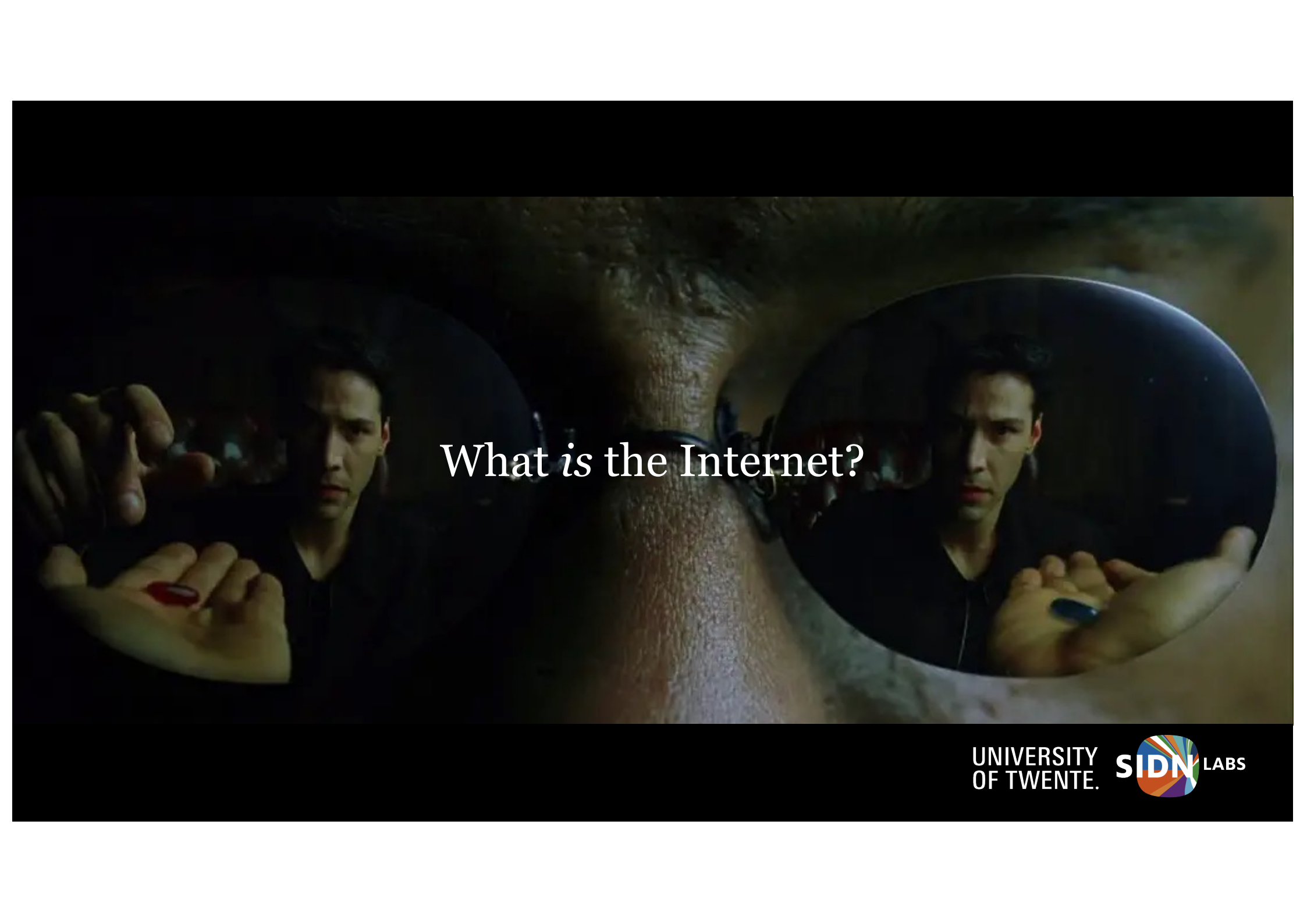


Today's objective

- Provide an overview of the past, present, and future of the Internet
- Enable you to impress your friends :-)

Agenda

- What is the Internet and how does it work (roughly)?
- A short history of the Internet
- Today's Internet
- The Internet of the future: 4 key challenges
- Example challenge: getting ready for quantum computers (if time permits)
- Questions and discussion

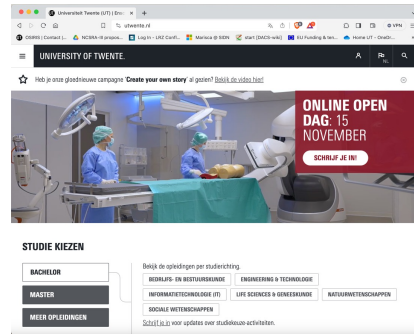
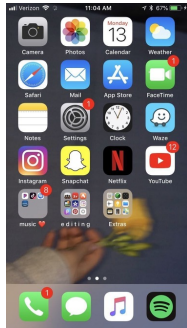


What is the Internet?

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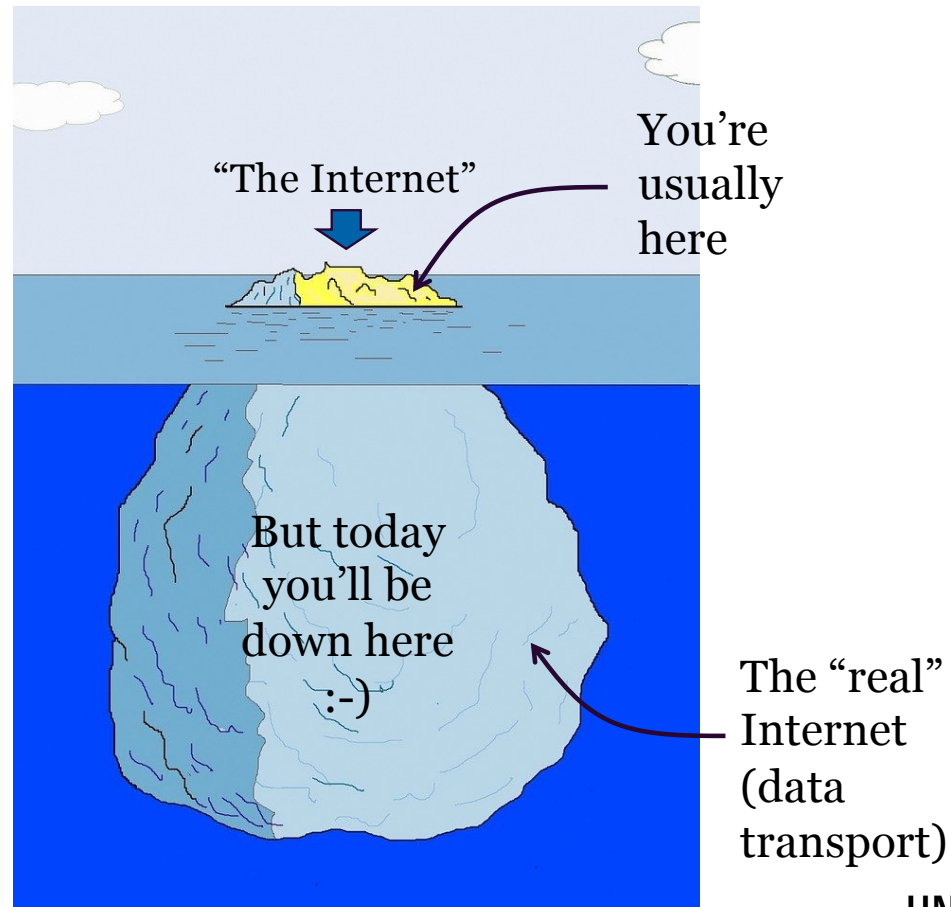
This is how most people see the Internet



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But that's just the tip of the iceberg



Barrett Lyon / The Opte Project
Visualization of the routing paths of the Internet
<https://www.opte.org/the-internet>

A complex and ever-changing
network of networks
(hence *internet*)

How does the Internet work?



Key concepts of inter-networking

A note on
Inter-Network Naming, Addressing, and Routing

John F. Shoch

January 1978

Xerox Palo Alto Research Center
Palo Alto, California 94305

Introduction

Taxonomies and terminology will not, by themselves, solve some of the difficult problems associated with the inter-connection of computer networks; but carefully choosing our words can help us to avoid misunderstanding and refine our perceptions of the task.

In 'Through the Looking Glass', the White Knight tries to elucidate (for an imprecise Alice) the important differences between what a song **is**, what it **is called**, what it **is named**, and what **the name is called**; perhaps we need to be equally vigilant with our use of the words 'name', 'address', and 'route'.

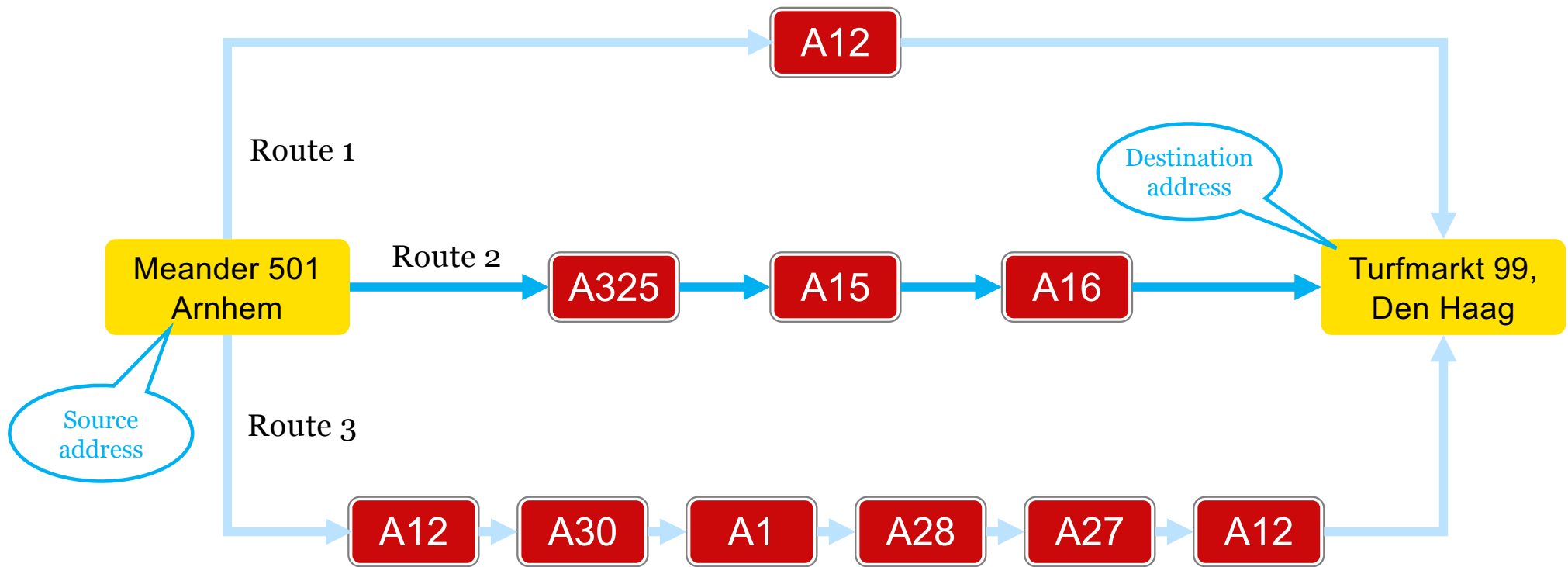
Let me offer one scheme which has proven useful in analyzing this domain, and begin by asserting that 'names', 'addresses', and 'routes' are different entities. [Even one of my favorite papers introduces part of this topic by merging two of these characteristics: "The question of addressing. or how to name all the participants in an interconnected communication system...."]

The General Model

We can first construct an extremely general definition:

The 'name' of a resource indicates **what** we seek,
an 'address' indicates **where** it is, and
a 'route' tells us **how to get there**.

Routing and addressing is like navigation

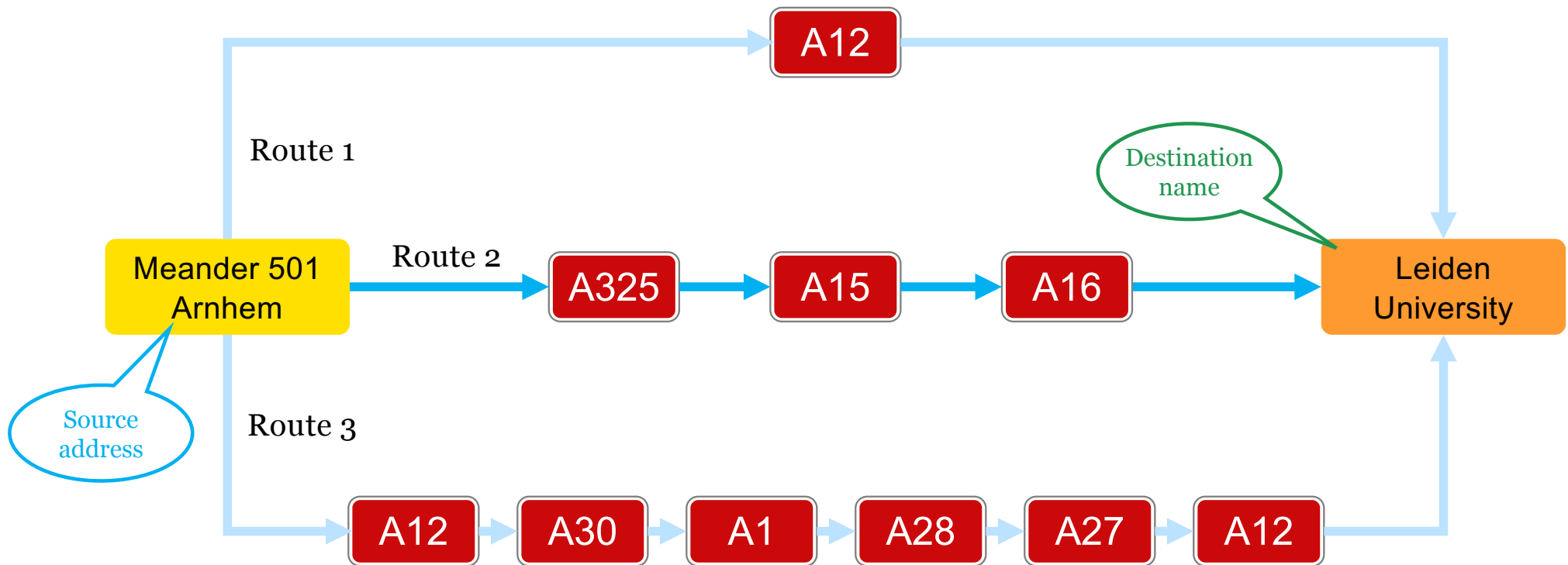


Highway $\approx$ network
Destination address $\approx$ IP address like 94.198.159.35

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Naming is like using a bookmarked destination

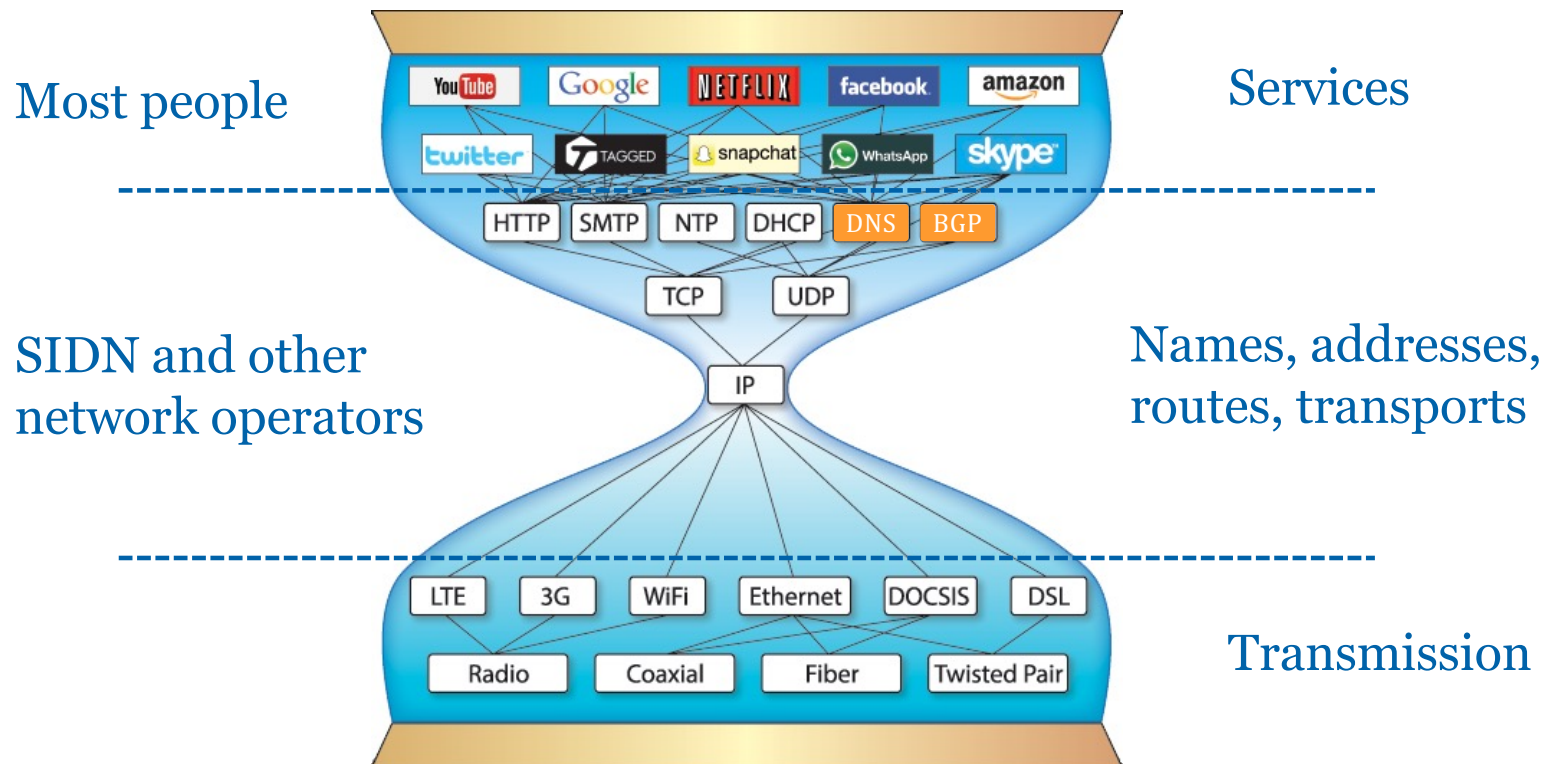


Destination name $\approx$ domain name
like `www.example.nl`

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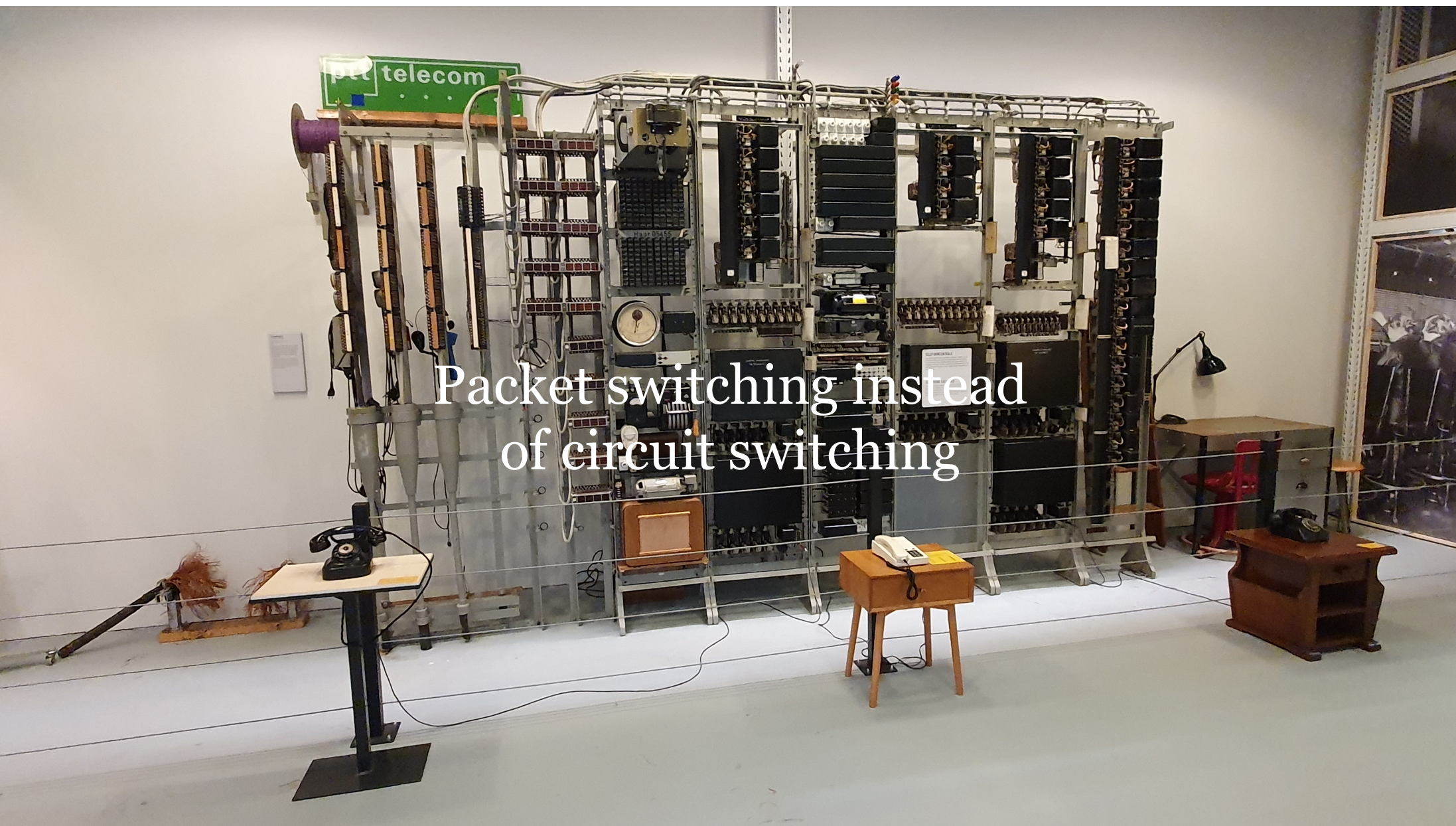
Protocols and services make that all happen



A vintage beige computer monitor and keyboard are centered on a white surface. The monitor is a CRT type with a wide bezel. The screen is dark, and the text "A short history of the Internet" is displayed in a white serif font. The keyboard is a full-sized beige model with a numeric keypad. The entire setup is against a plain white background.

A short history of the Internet

Packet switching instead
of circuit switching



IEEE MILESTONE IN ELECTRICAL ENGINEERING
AND COMPUTING

Birthplace of the Internet, 1969

At 10:30 p.m., 29 October 1969, the first ARPANET message was sent from this UCLA site to the Stanford Research Institute. Based on packet switching and dynamic resource allocation, the sharing of information digitally from this first node of ARPANET launched the Internet revolution.

October 2009



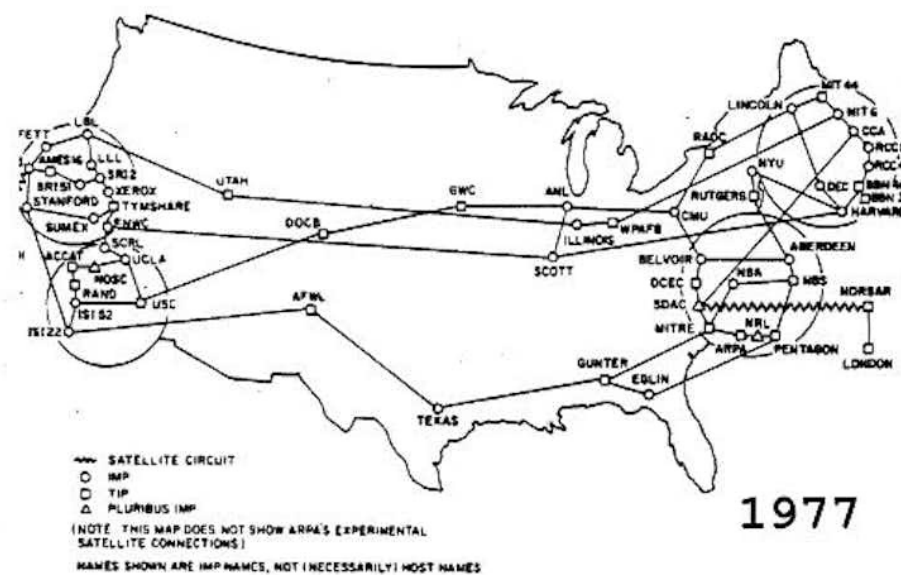
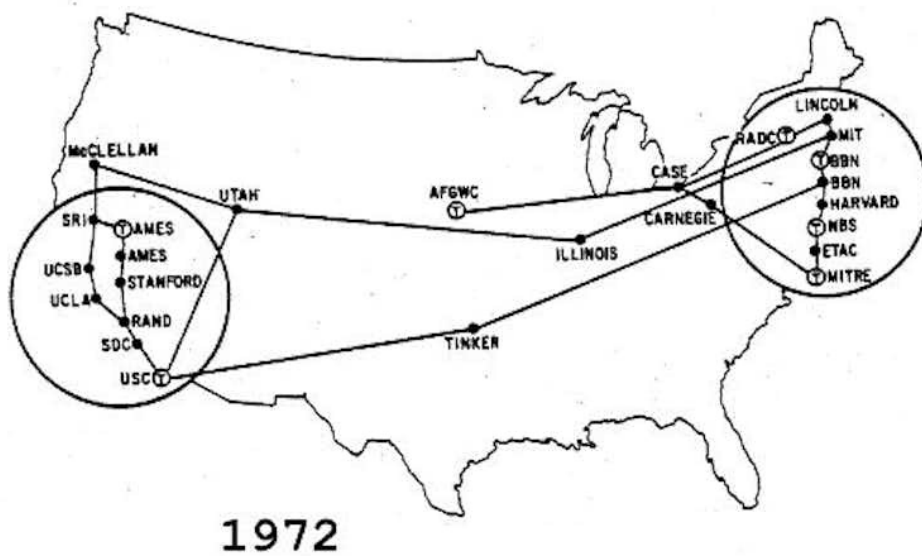
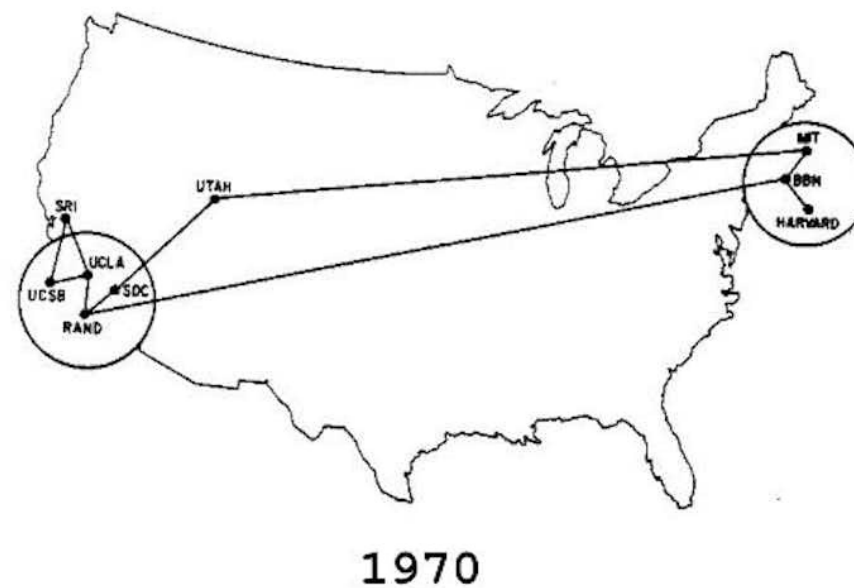
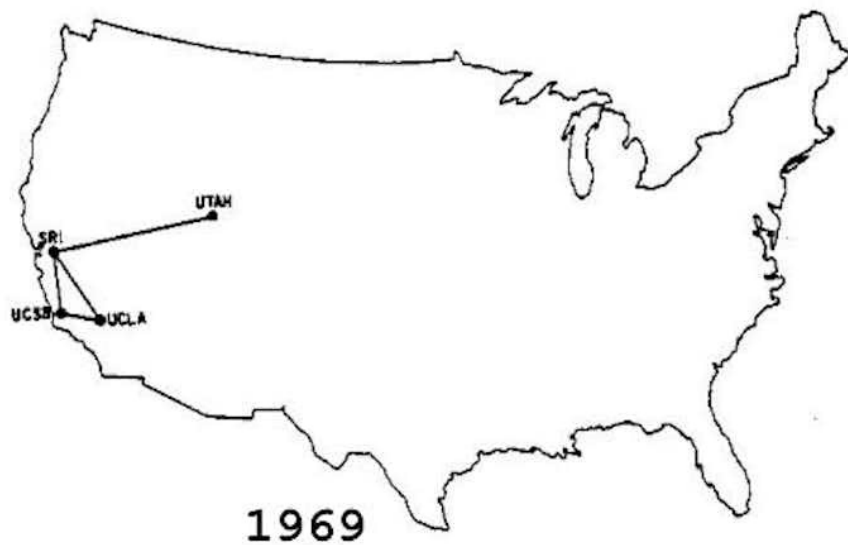


Visit to the Birthplace of the Internet @UCLA, September 2017

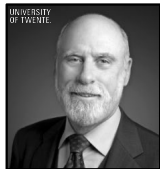


Birthplace of the Internet, UCLA

<https://www.washingtonpost.com/sf/business/2015/05/30/net-of-insecurity-part-1/>



Early days: personal trust and no “bad actors”



Vint Cerf



Steve Crocker



Robert Kahn



Jon Postel



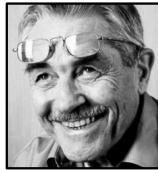
Leonard Kleinrock



Paul Mockapetris



Kc Claffy



Louis Pouzin



Kees Neggers



Jaap Akkerhuis

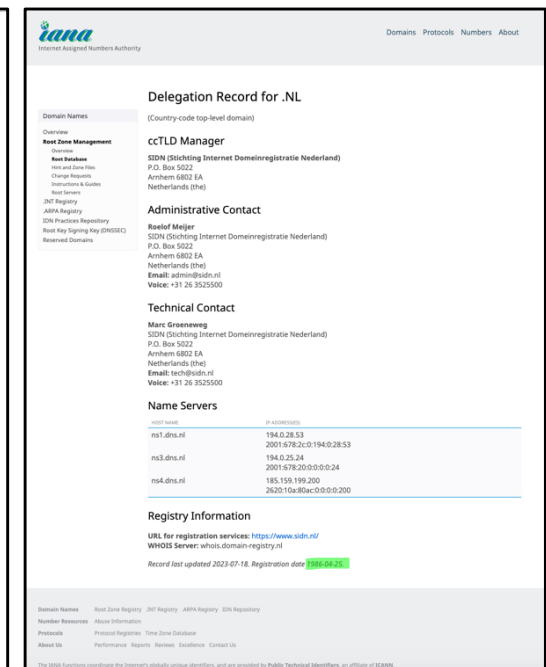
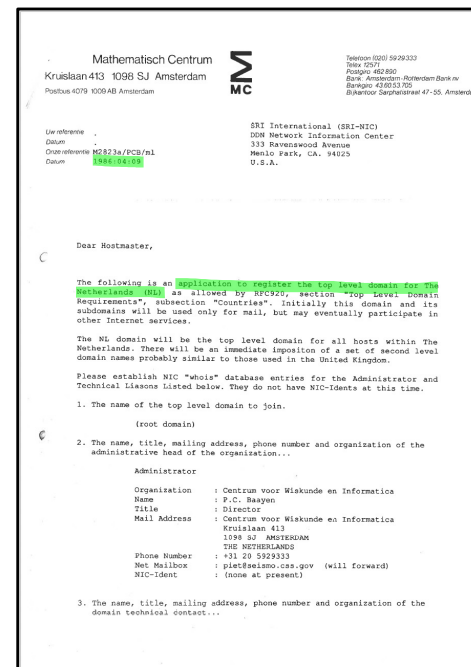


Erik Huizer

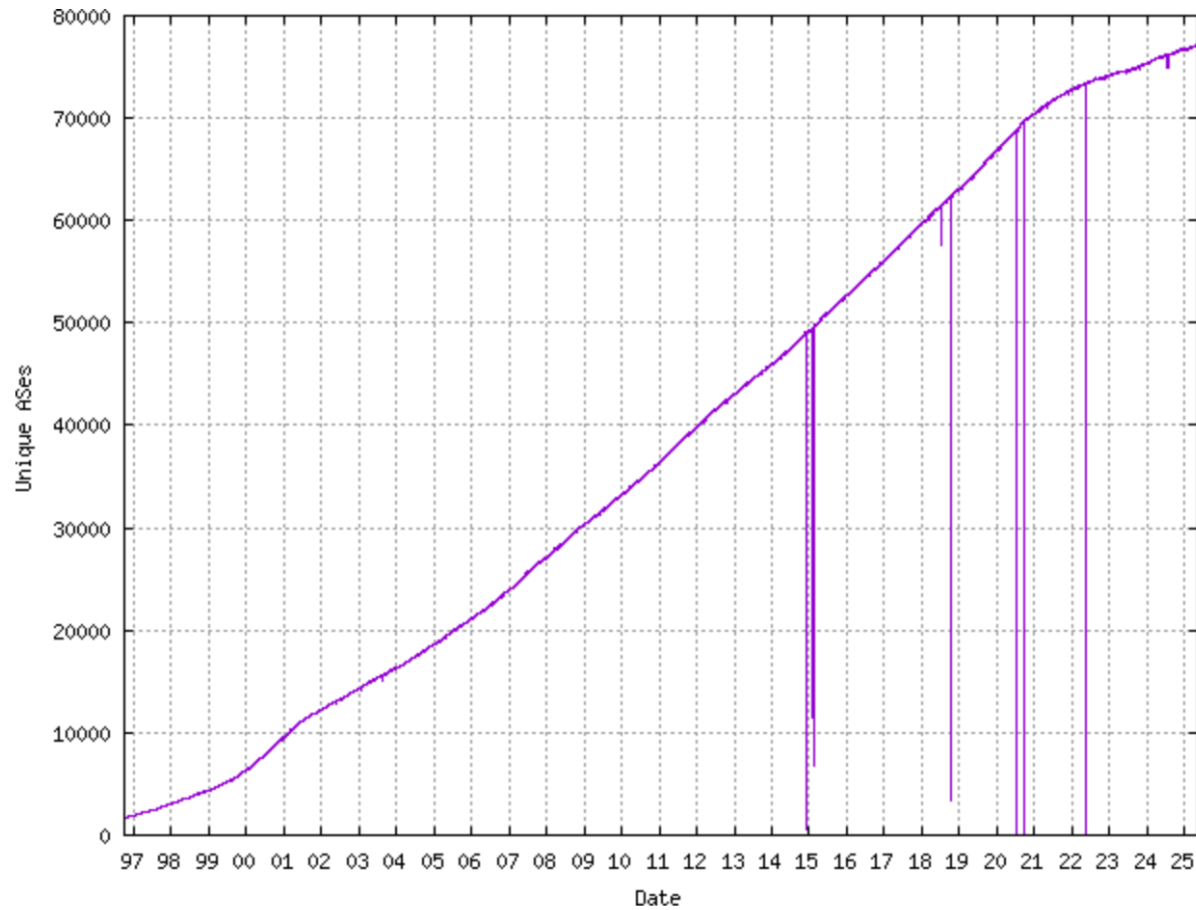


Daniel Karrenberg

.nl delegation (April 25, 1986)



Internet growth 1996-2025

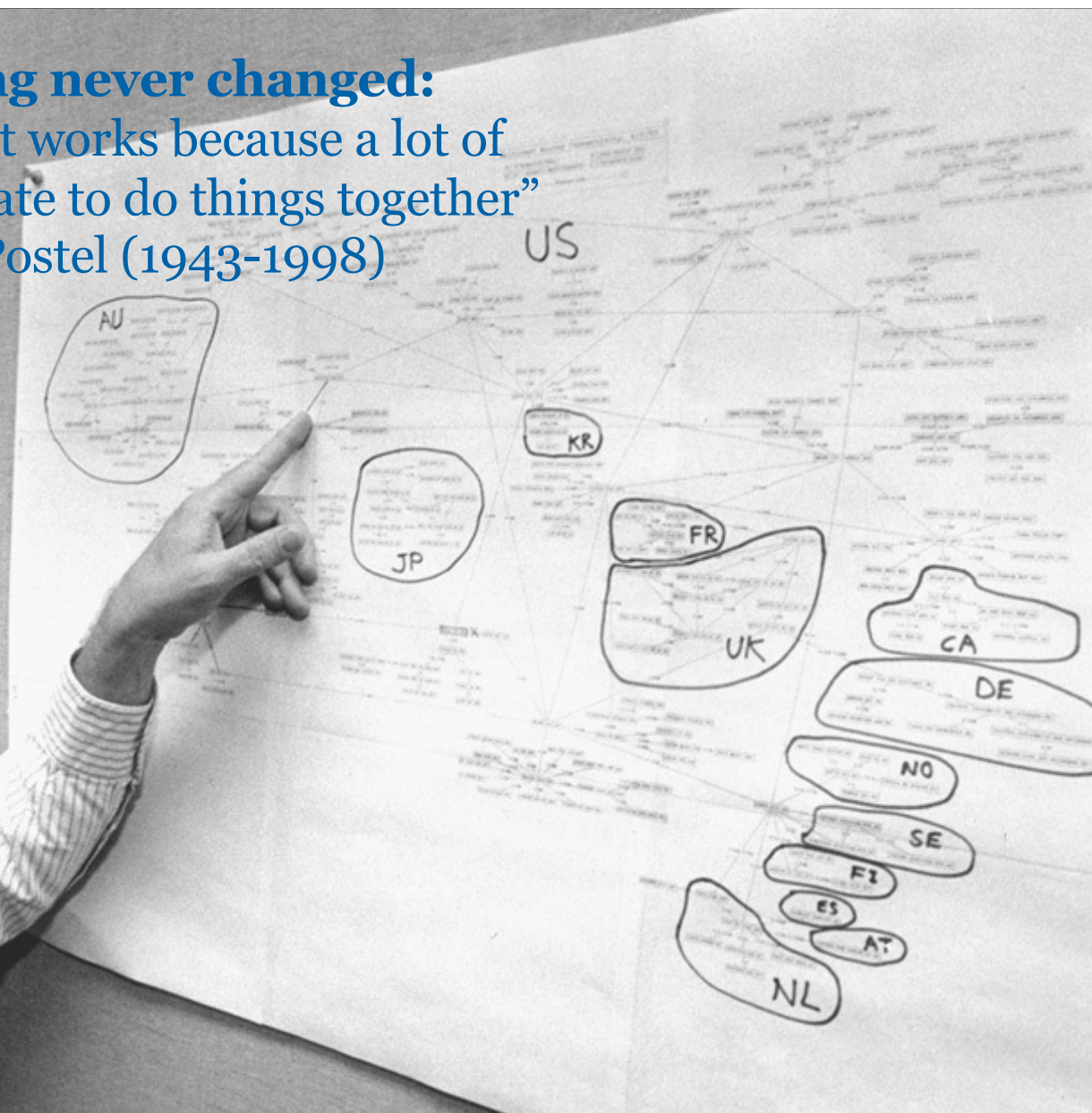


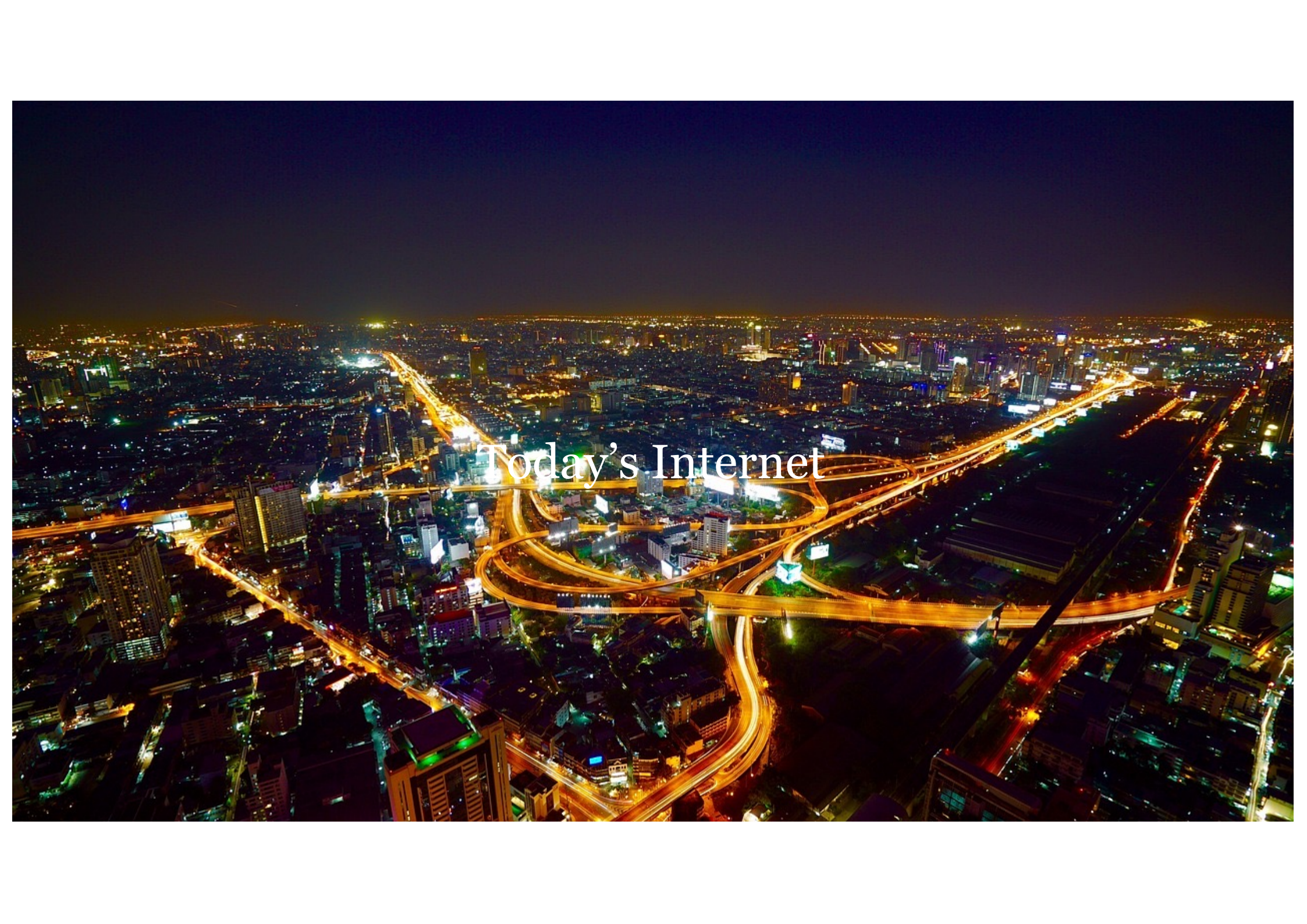
<https://www.cidr-report.org/as2.0/>

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One thing never changed:
“The Internet works because a lot of
people cooperate to do things together”
– Jon Postel (1943-1998)



An aerial night photograph of a city, likely in Asia, showing a dense urban landscape with numerous skyscrapers and residential buildings. A prominent feature is a large, multi-level highway interchange with several overpasses and ramps, illuminated by streetlights. The city lights create a vibrant, glowing effect against the dark night sky. The text "Today's Internet" is overlaid in the center of the image in a white, serif font.

Today's Internet

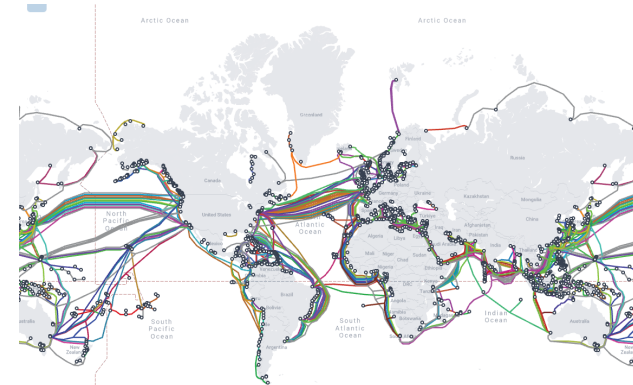
The tangible Internet today



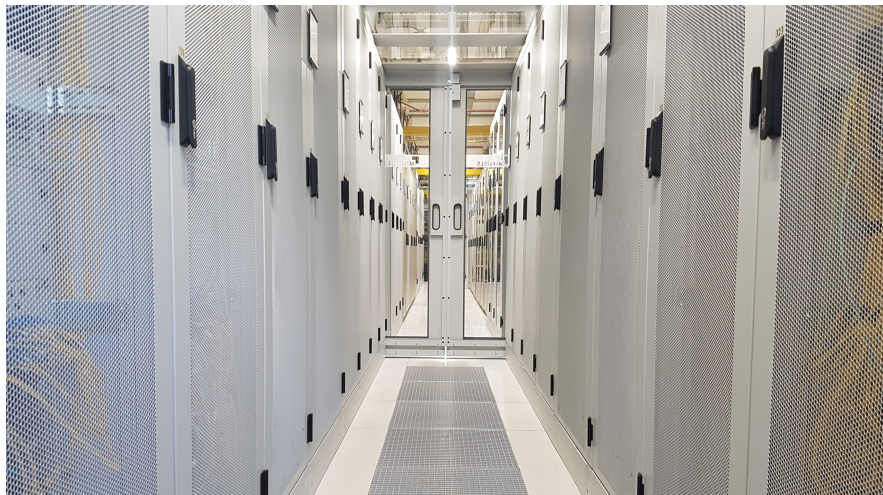
Nokia router



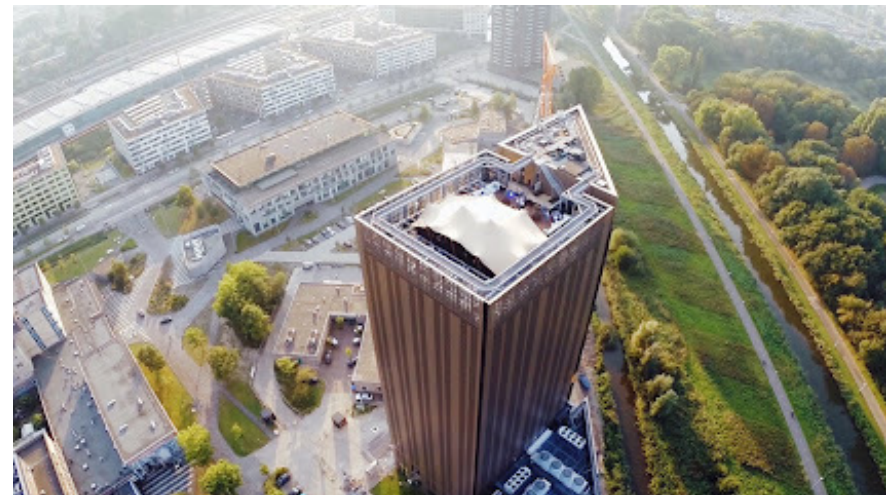
GL-iNet mini router



<https://www.submarinecablemap.com/>



Nikhef data center, Amsterdam



Data Tower, Amsterdam Science Park

The Internet is our newest civil infrastructure

- Large, built over multiple generations
- Continual improvement, no replacement
- Interacting components with interfaces
- Foundation for other civil infrastructures

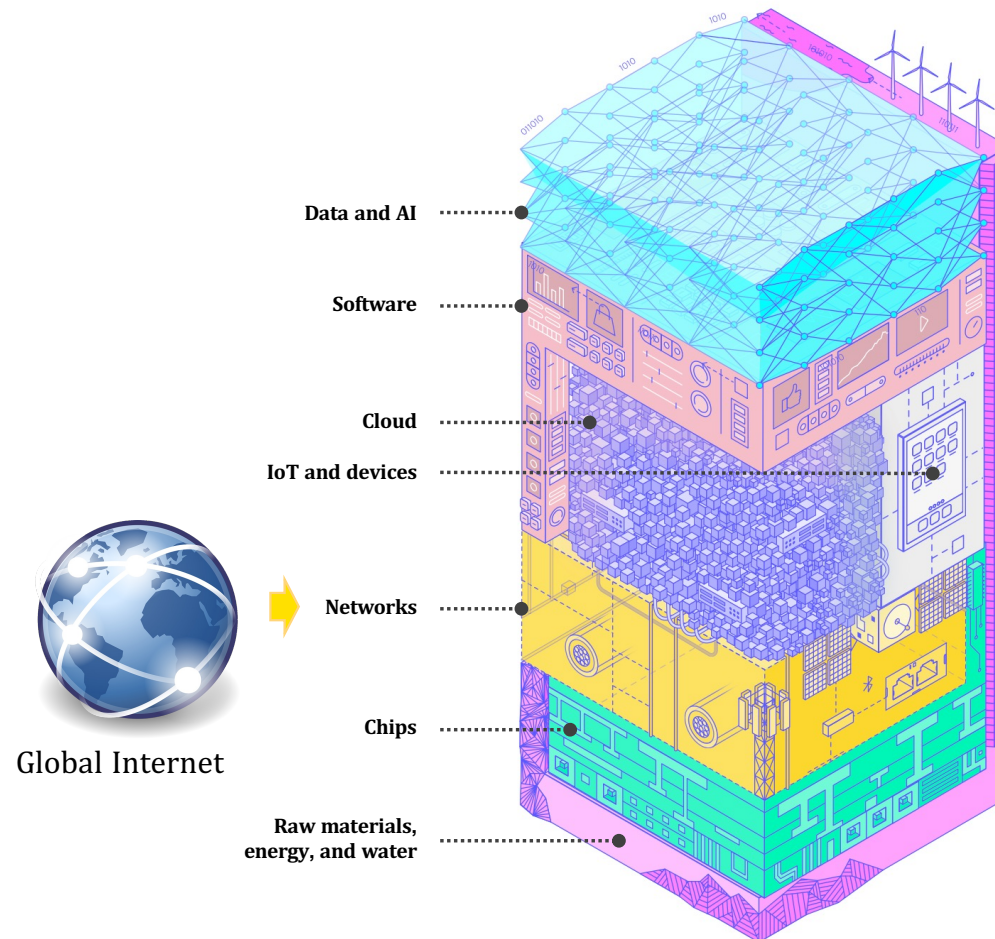


Henning Schulzrinne, “Networking: The Newest Civil Engineering Challenge”, SIGCOMM Lifetime Achievement Award keynote, SIGCOMM 2022, Amsterdam, August 2022, https://www.youtube.com/watch?v=5lvXIqI_mQ4

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An essential part of our technology stack



<https://www.euro-stack.info>
<https://www.arte.tv/de/videos/120435-000-A/droht-der-digitale-blackout/>

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Reinforce global Internet and European infrastructure



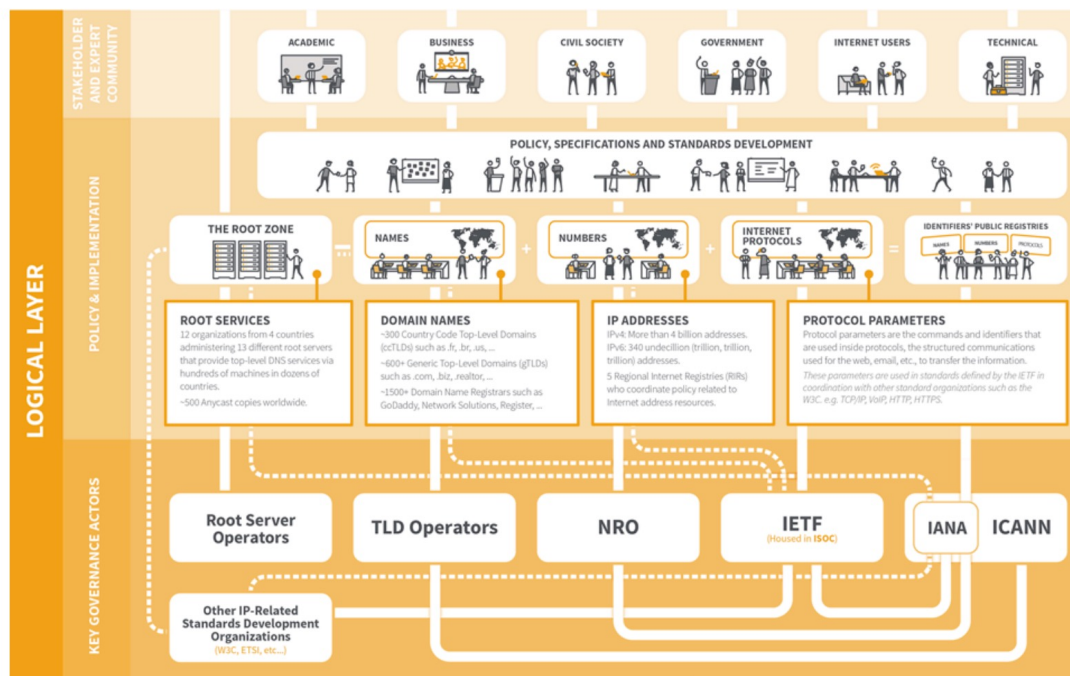
Global Internet

		KEY COUNTRIES				KEY FIRMS	
Data and artificial intelligence		 US		 China		OpenAI, Microsoft, Google, Meta, Anthropic, XAI, Amazon, Baidu, Tencent, Alibaba, DeepSeek	
		 US	 China	 Germany		Microsoft, Apple, Alphabet, Meta, Amazon, Salesforce, SAP, ByteDance, Tencent	
Cloud		 US		 China		Amazon, Microsoft, Alphabet, Alibaba	
Internet of things & devices		 US	 China	 Korea	 Germany	Amazon, Google, Apple, Samsung, Huawei, Bosch, Siemens, Xiaomi	
Networks		 US	 China	 Europe	 Japan	Huawei, Nokia, Ericsson, ZTE, SpaceX, NEC	
Chips		 Taiwan	 Korea	 US	 Netherlands	TSMC, Samsung, Intel, NVIDIA, AMD, ASML	
Raw materials, energy, and water		 US		 China		 Russia	Chinese government (through SOEs e.g., China Rare Earth Group), ExxonMobil, Gazprom

Multi-stakeholder coordination and governance

THE LOGICAL LAYER OF DIGITAL GOVERNANCE

Layered on top of the Physical Infrastructure's thousands of networks and satellites, the Internet's Logical Layer is what delivers One Internet for the world through Unique Identifiers (Names, Numbers, and Protocol Parameters). ICANN coordinates the administration of this layer in partnership with other technical communities to ensure the security, stability, resiliency, and integrity of this critical layer.



<https://www.icann.org/en/system/files/files/ssr-framework-fy15-16-30sep16-en.pdf>

NL IGF
NEDERLANDS INTERNET GOVERNANCE FORUM



EuroDIG
European Dialogue on Internet Governance



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https://labs.ripe.net/author/hisham_ibrahim/why-effective-digital-governance-begins-with-understanding-the-internet-itself/

Open policymaking, standardization, and operation

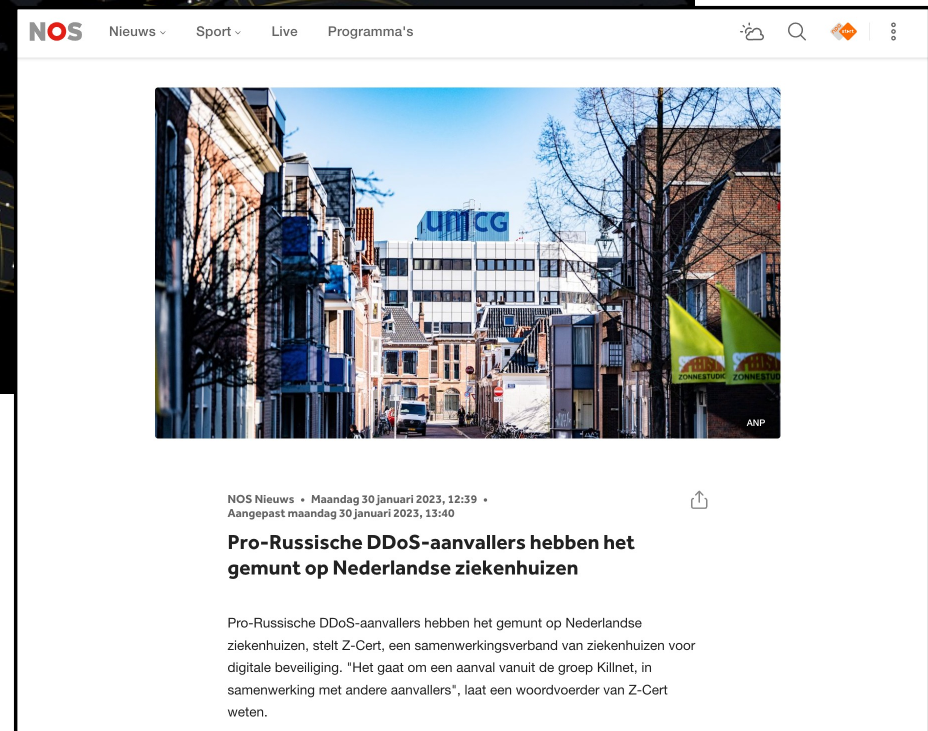
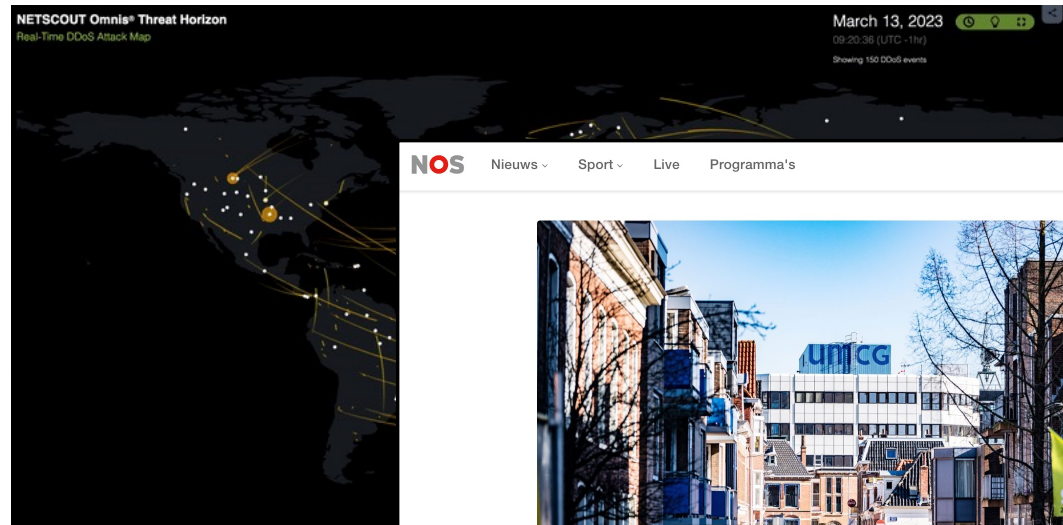


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Key issue: Internet security

- Phishing
- Fake webshops
- DDoS attacks
- Routing hijacks
- Quantum computers



A photograph of an ice climber ascending a steep, blue-tinged ice wall. The climber is wearing a blue jacket, black pants, and a red helmet. They are equipped with ice axes and crampons. The background shows a vast, icy landscape under a bright sky.

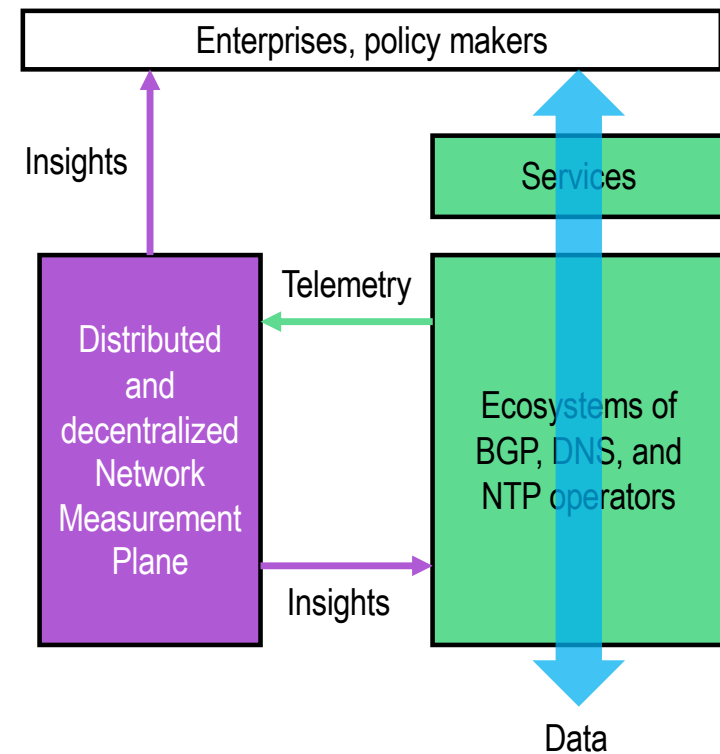
The Internet of the future: 4 key challenges

Challenge #1: security and robustness of core systems

- Incentivize adoption of technologies such as DNSSEC, DoH, ROA, ROV, NTS, for instance through internet.nl and MANRS
- Evaluate operational impact of PQC algorithms on DNSSEC, RPKI, standardize (NIST/IETF), and develop software and best-practices to deploy them
- Increase robustness of deployments, for instance by automating the deployment of DNS anycast infrastructures based on continuous measurements
- Further develop technologies such as BGPsec and ASPA as well as entirely new concepts such as “risk-based routing” and “zones of trust” (cf. challenge #3)

Challenge #2: measurement plane for Internet security

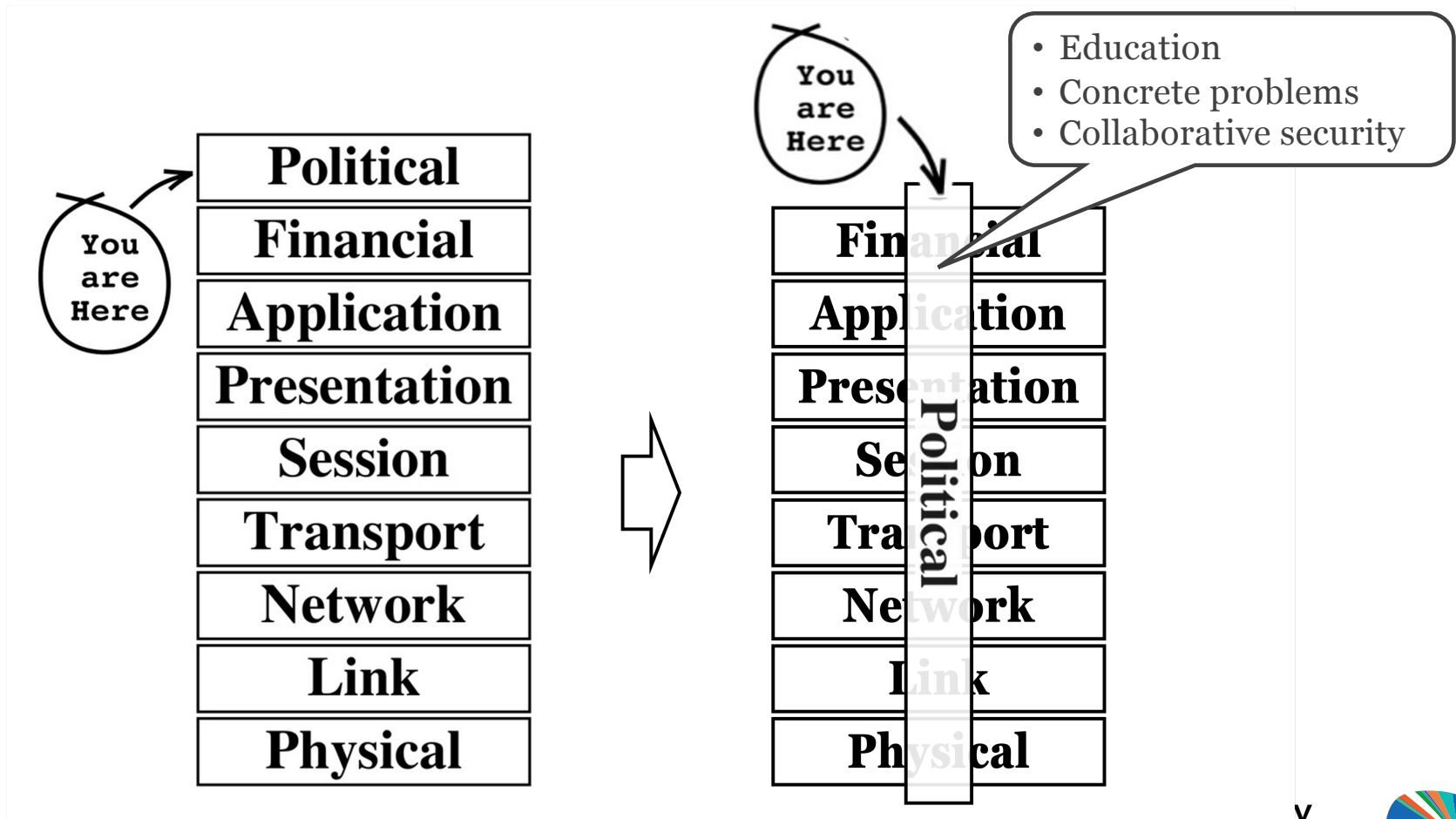
- Continually map the Internet's behavior and evolution: routing, DNS, time, certificates
- Input for collaborative incident response handling, infrastructure engineering, and policy making
- Ultimately discover and share data across operators and researchers in an interoperable and federated way



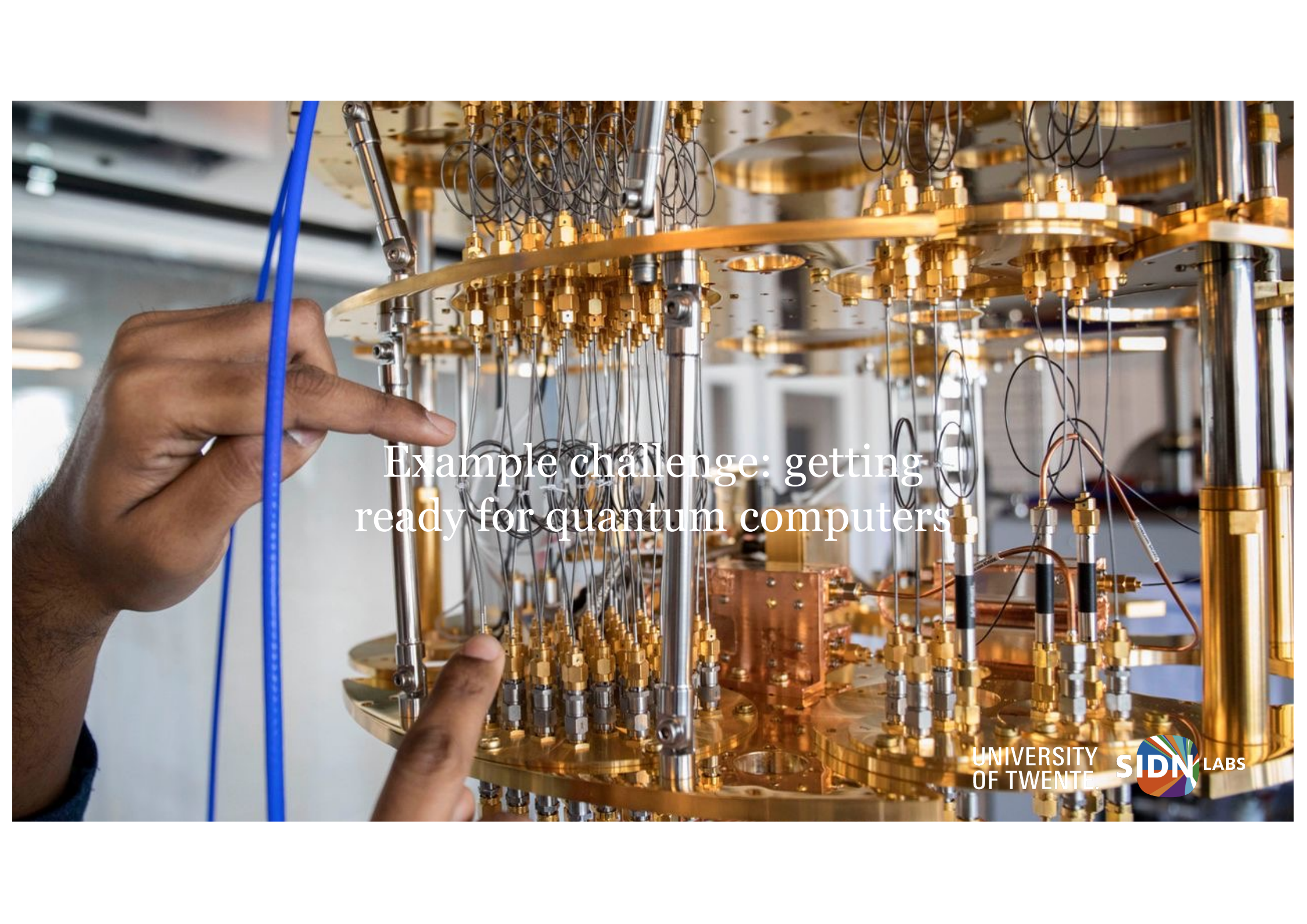
Challenge #3: develop new network security concepts

- Policy domains: groups of networks that agree on a “networking regime”, while staying fully connected to the rest of the Internet
- Allows for incremental deployment of stronger security properties, such as path attestation for remote train driving and intelligent transport systems
- New forms of routing, such as “risk-based routing” or “green routing” – but what will that do to the overall robustness and scalability of the Internet?
- New types of architectures, such as SCION and the Responsible Internet

Challenge #4: Internet governance and technology



<https://www.hesselman.net/blog.html#GovernanceTechnologyExperts>

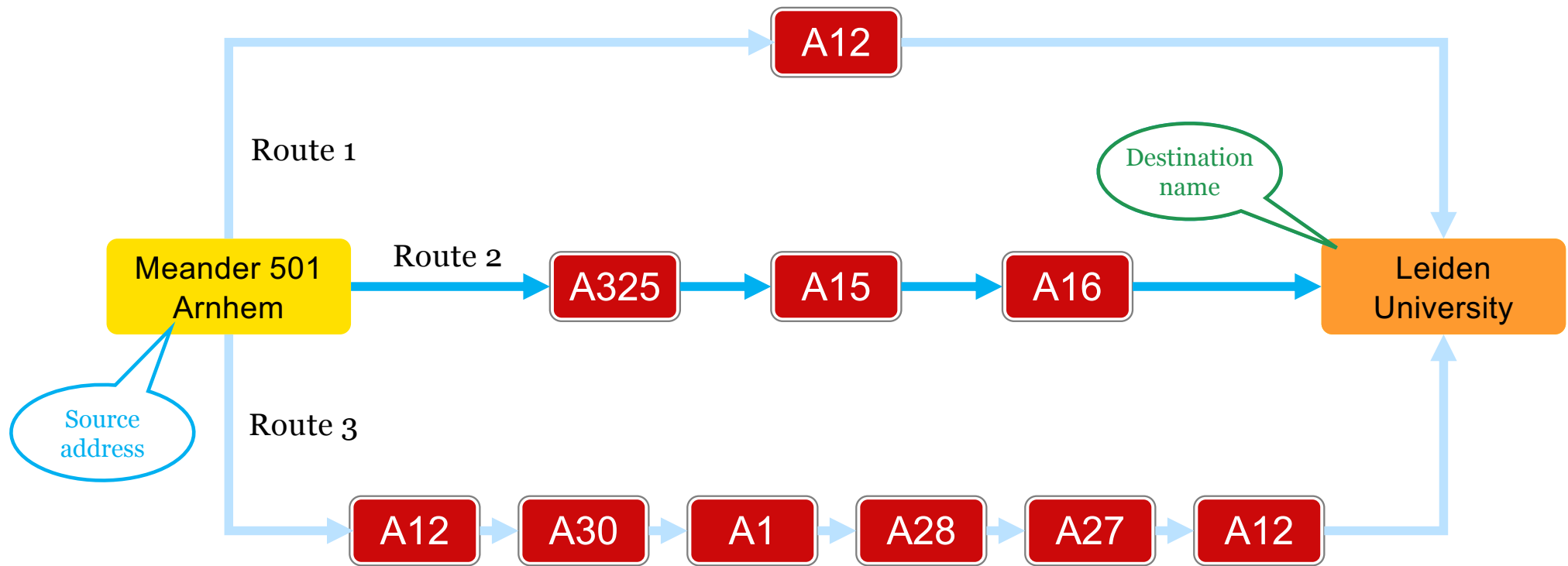


Example challenge: getting
ready for quantum computers

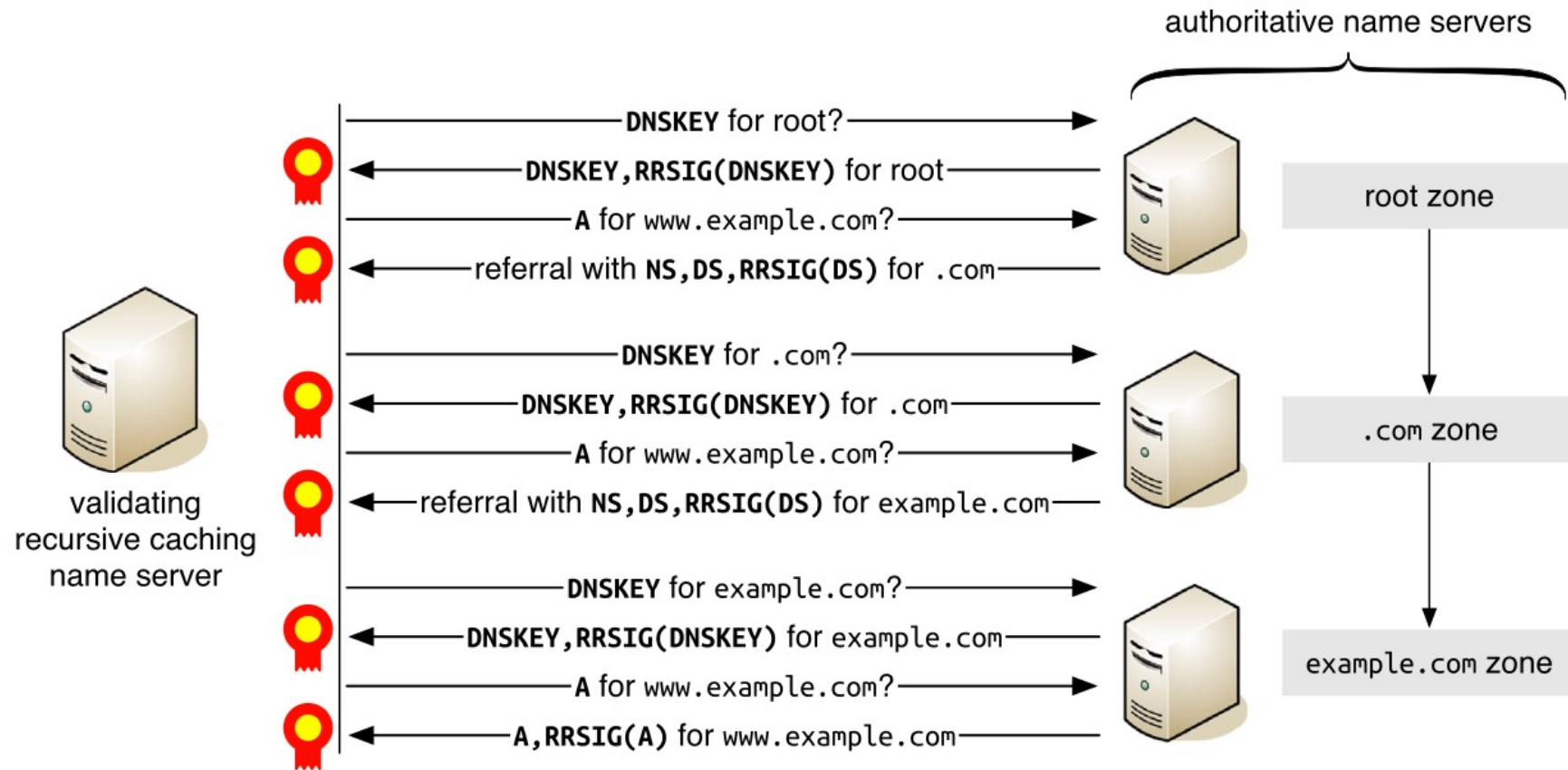
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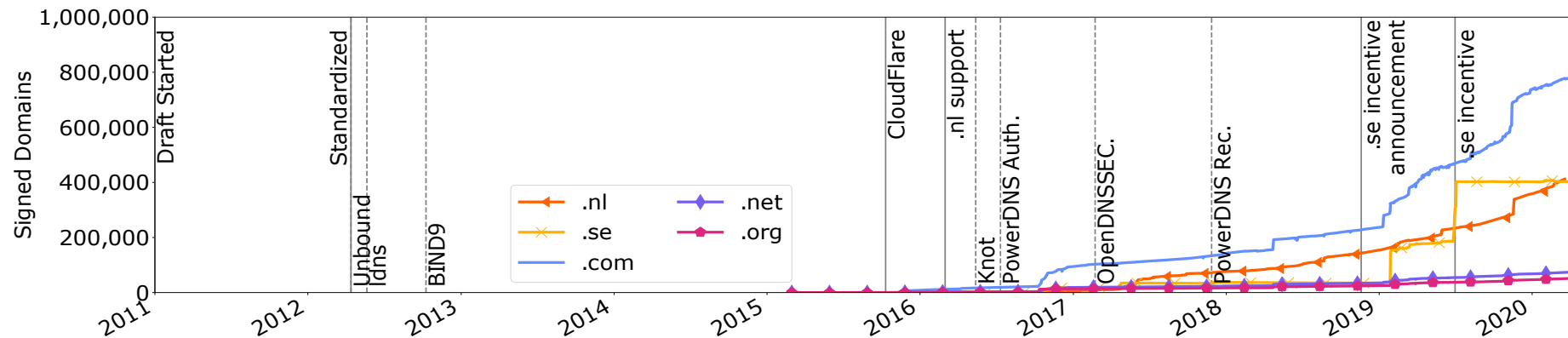
The Internet as highway network revisited



DNSSEC keys and signatures need PQC



Why work on PQC in DNSSEC now?



Domains signed with ECDSA256 and resolvers able validating this algorithm

Requirements for quantum-safe algorithms

Prio	Requirement	Good	Accepted Conditionally
#1	Signature Size	$\leq 1,232$ bytes	—
#2	Validation Speed	$\geq 1,000$ sig/s	—
#3	Key Size	≤ 64 kilobytes	> 64 kilobytes
#4	Signing Speed	≥ 100 sig/s	—

M. Müller et al, "Retrofitting Post-Quantum Cryptography in Internet Protocols: A Case Study of DNSSEC", ACM SIGCOMM Computer Communication Review, vol. 50, no. 4, 2020.

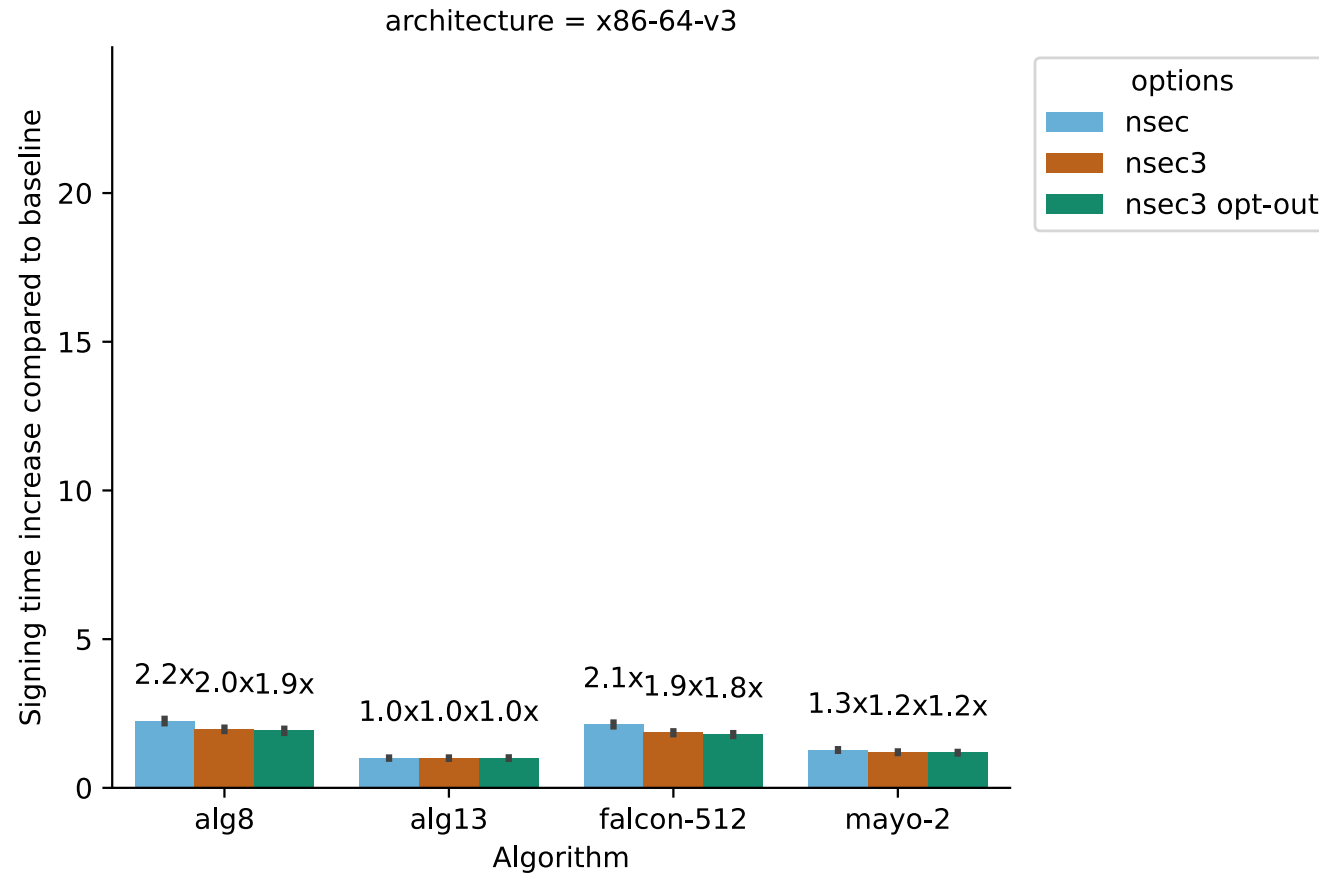
PQC algorithm	ECC	MAYO	SQSign	Falcon
Signature size	😊😊	😊	😊😊	😞
Validation speed	😊	😊	😞	😊
Key size	😊😊	😞	😊😊	😊
Signing speed	😊	😊	😞	😊

Post-quantum signatures zoo: <https://pqshield.github.io/nist-sigs-zoo>

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Signing performance looks good



C. Schutijser, R. Koning, E. Lastdrager, C. Hesselman, "Evaluating Post-Quantum Cryptography in DNSSEC Signing for Top-Level Domain Operators", Traffic Measurements and Analysis conference (TMA2025), June 2025

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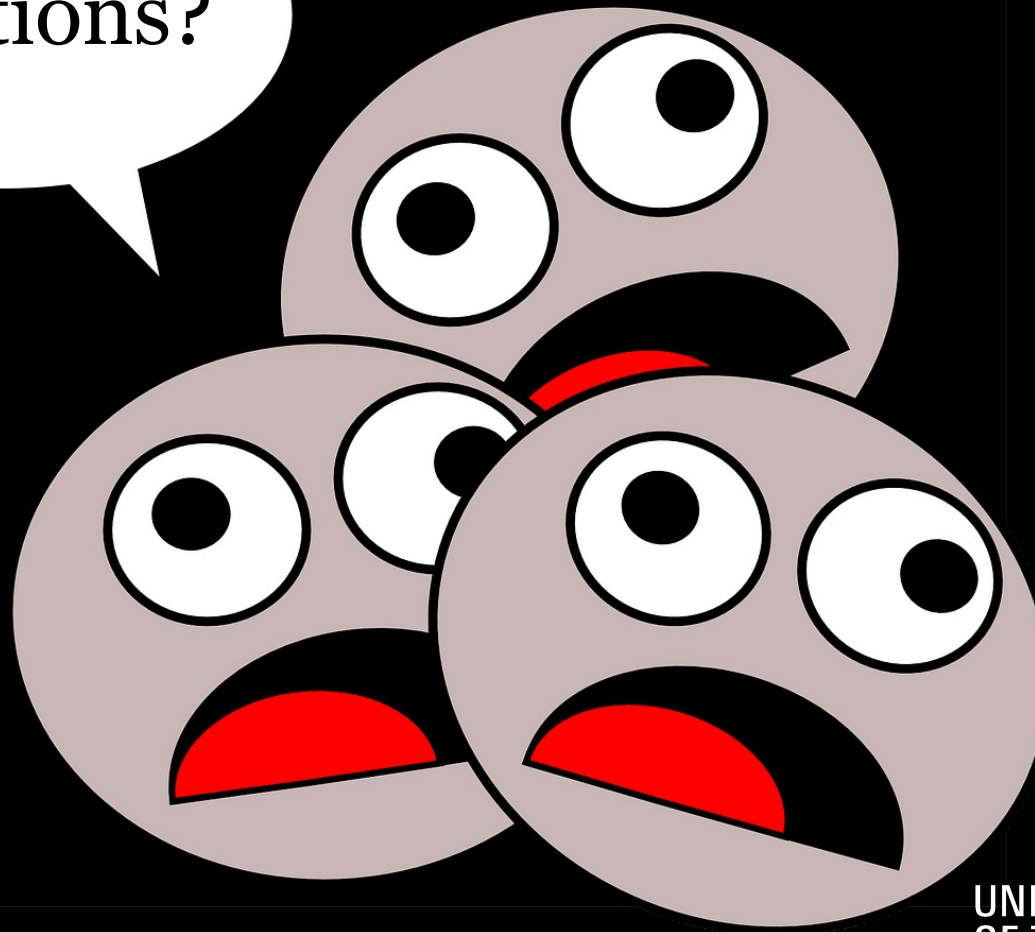
A large, bold, black stylized letter 'Z' is centered on a light blue background. The letter has a modern, slightly curved design.

Adding it all up

Key takeaways

- The Internet is our newest civil infrastructure, but this time it's a global one
- Internet security is a joint responsibility
- Challenges to increase Internet security, such as for future applications
- Education, academic and applied research are essential to make all that happen
- Starting today with *Hoe Het Net Werk(t)* ☺

Questions?



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www.sidnlabs.nl | stats.sidnlabs.nl



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