

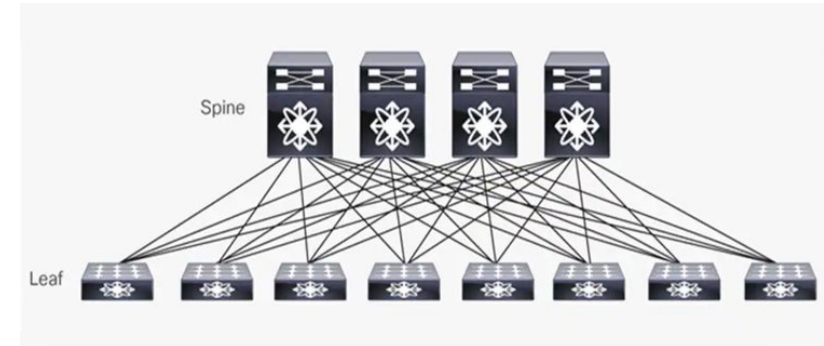
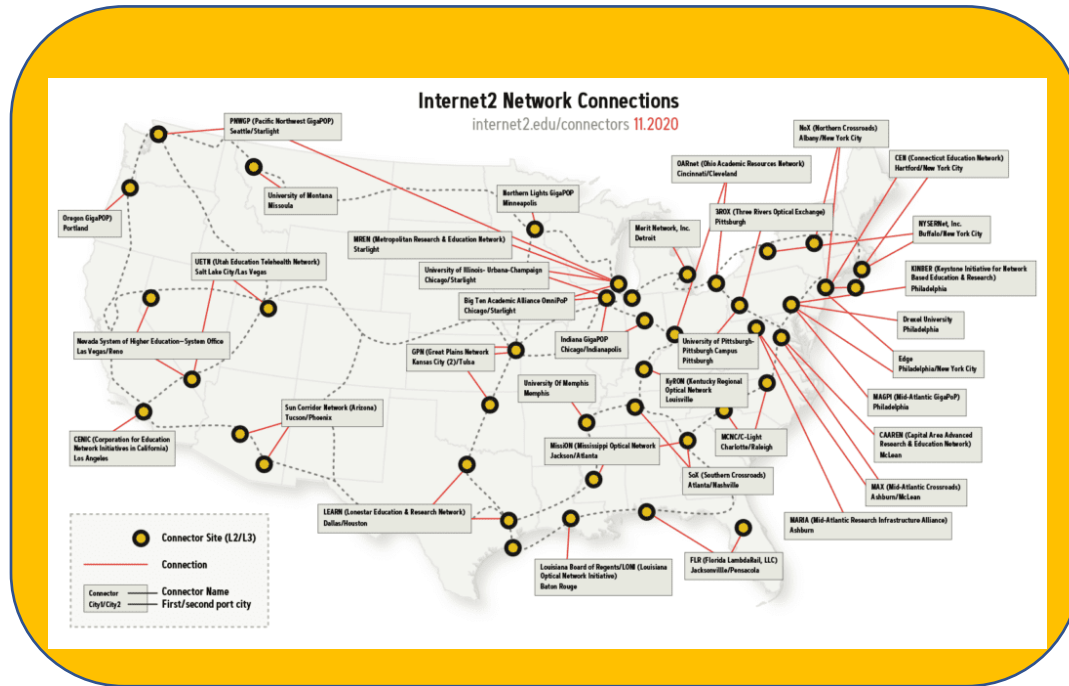
# Networking: The Newest Civil Engineering Challenge

Henning Schulzrinne  
(Columbia University)  
SIGCOMM 2022 - Amsterdam  
August 2022

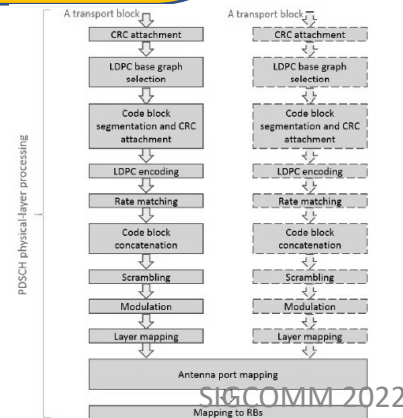
# A retro-perspective into the future

- Networking is really four fields
- Networking is civil (infrastructure) engineering
- We're no longer "new" – adult hood (and middle age+) is painful
- Standards make networking different – but the valley of death looms
- Responsible AI → responsible networking
- Networking is no longer *the* (PhD) student attractor
- Internet literacy (not just skills) is our next challenge

# Networking has become (at least) four areas



PHY



# Networks as core civil infrastructure



Civil infrastructure systems involves the design, analysis and management of *infrastructure that supports human activities*, such as **electric power, oil and gas, water and wastewater, communications, transportation and the buildings that make up urban and rural communities.** These networks deliver essential services, provide shelter and **support social interactions and economic development.** They are society's lifelines.

# The great civil infrastructures

- Constructed over generations
- Not replacement, but continual refurbishment
- Interdependent components with well-defined interfaces
- High initial cost, but operating cost dominates

water



energy



internet communications



transportation



# The Internet as core civil infrastructure

For Immediate Release

February 12, 2013

## Executive Order -- Improving Critical Infrastructure Cybersecurity

EXECUTIVE ORDER

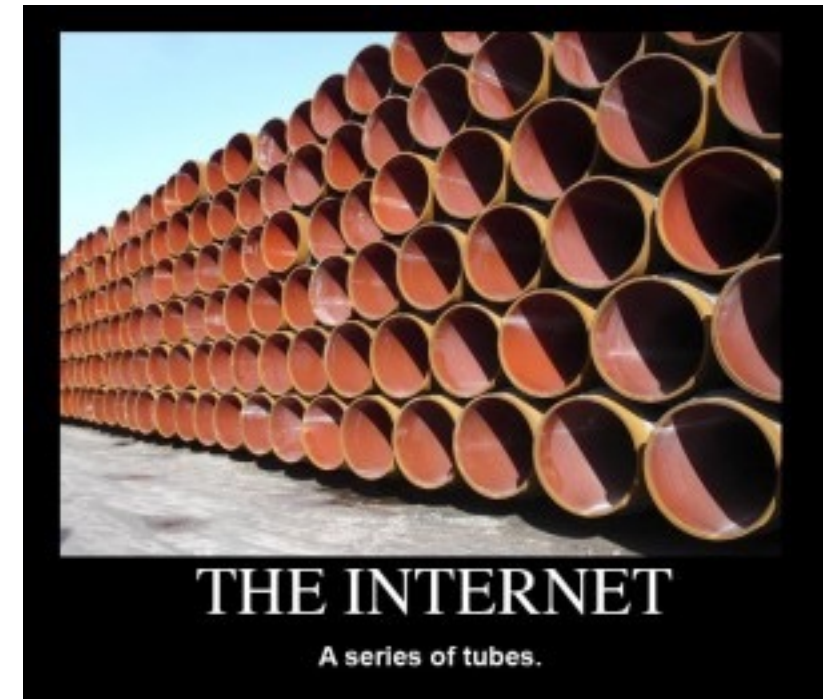
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### IMPROVING CRITICAL INFRASTRUCTURE CYBERSECURITY

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

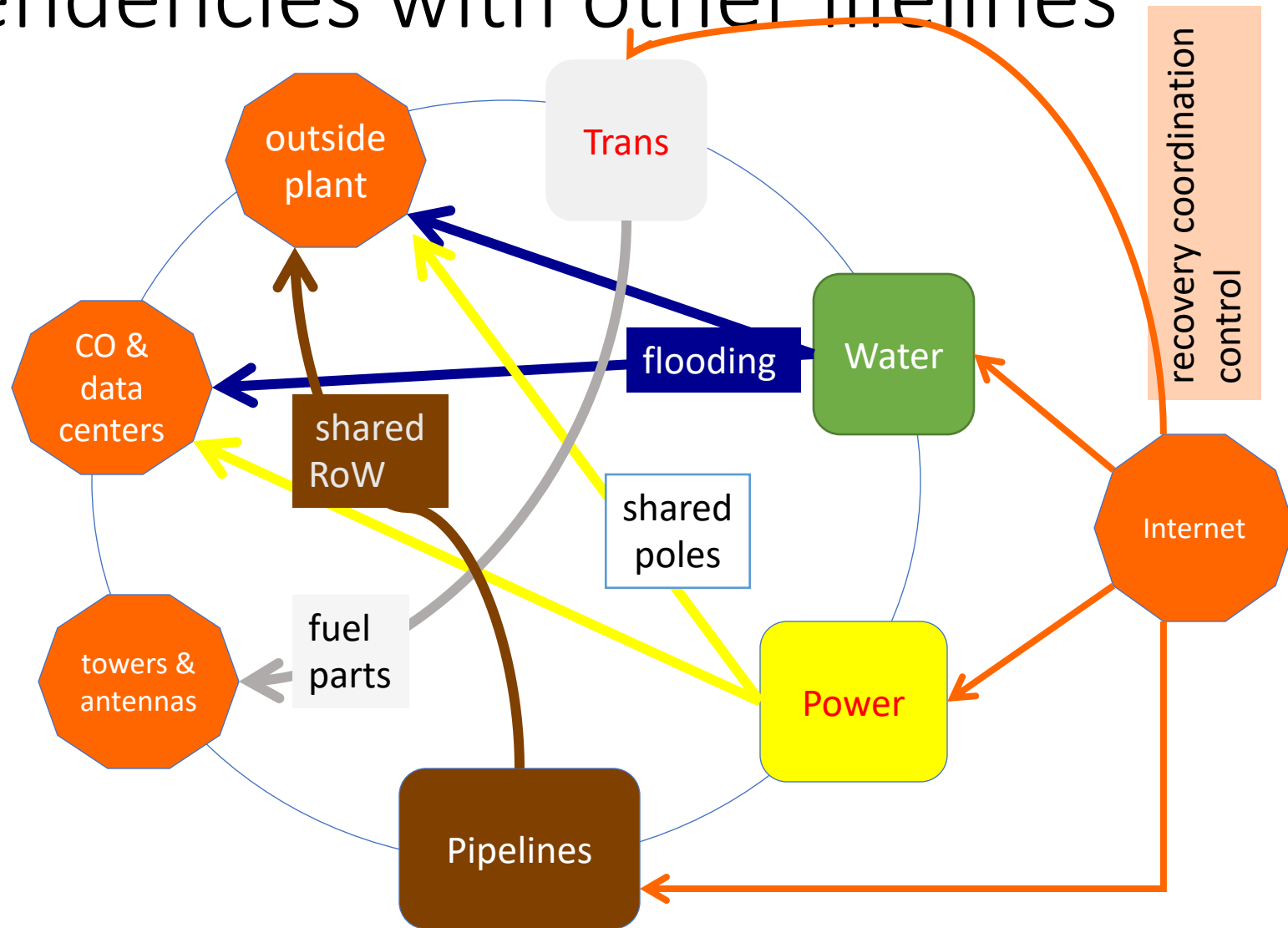
Section 1. Policy. Repeated cyber intrusions into critical infrastructure demonstrate the need for improved cybersecurity. The cyber threat to critical infrastructure continues to grow and represents one of the most serious national security challenges we must confront. The national and economic security of the United States depends on the reliable functioning of the Nation's critical infrastructure in the face of such threats. It is the policy of the

U.S. efforts shall address the security and resilience of critical infrastructure in an integrated, holistic manner to reflect this infrastructure's interconnectedness and interdependency. This directive also identifies energy and **communications systems** as uniquely critical due to the enabling functions they provide across all critical infrastructure sectors.



Ted Stevens (R-AK, 2006)

# Interdependencies with other lifelines



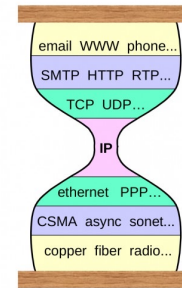
# Interfaces: Energy



110/220V



~1915 (2 prong)



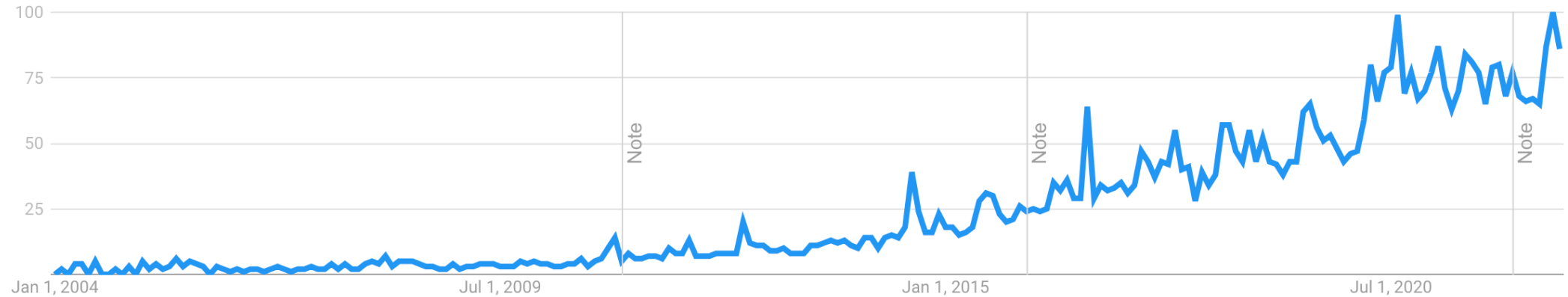
1901



Civil engineers care a lot about  
reliability & costs



# “Internet outage” trends



“All the News  
That’s Fit to Print”

# The New York Times

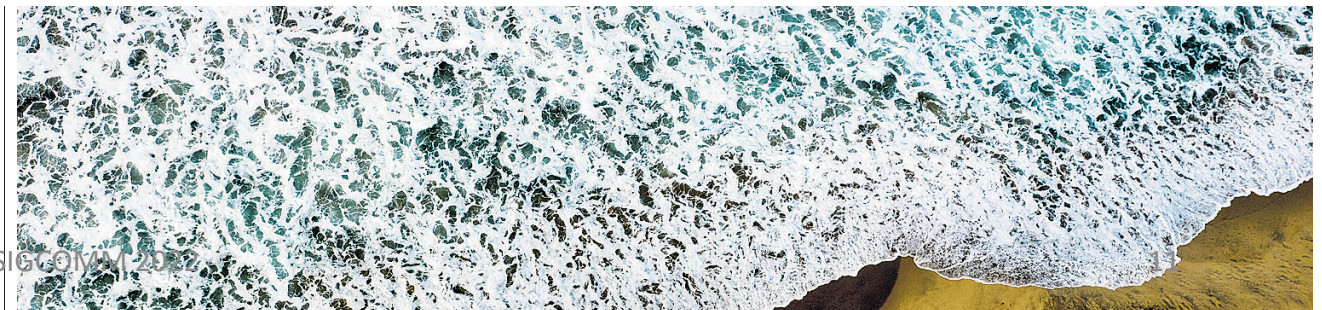
VOL. CLXXI . . . No. 59,202 +

© 2021 The New York Times Company

NEW YORK, TUESDAY, OCTOBER 5, 2021

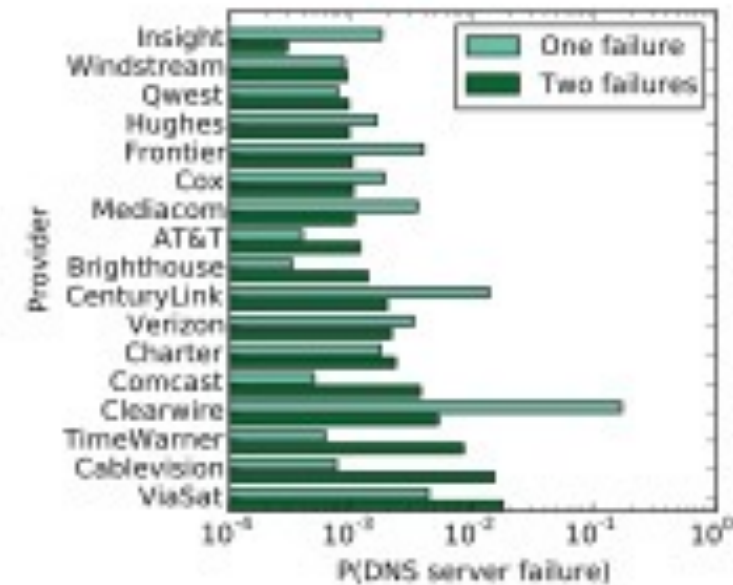
**Facebook Apps  
Crash, Leaving  
Billions Cut Off**

**Outage Lasting Hours  
Has Global Impact**



# Still working on those 5 nines – and we need to keep trying!

ISP	Average availability			Average annual downtime (hours)		
	1%	5%	10%	1%	5%	10%
<i>Fiber</i>						
Frontier (Fiber)	98.58	99.47	99.77	124	46.8	20.3
Verizon (Fiber)	<b>99.18</b>	99.67	99.80	72	29.2	17.8
<i>Cable</i>						
Bright House	98.21	99.28	99.58	156	62.8	36.7
Cablevision	98.33	99.53	99.70	146	41.4	25.9
Charter	97.84	99.29	99.59	189	62.5	36.1
Comcast	98.48	99.45	99.66	134	48.0	29.7
Cox	96.35	98.82	99.33	320	103.0	58.4
Insight	96.38	98.31	<b>98.94</b>	318	148.0	93.0
Mediacom	95.48	98.34	99.03	396	146.0	85.3
TimeWarner	98.47	99.48	99.69	134	45.9	26.9
<i>DSL</i>						
AT&T	96.87	99.05	99.42	274	83.3	51.1
CenturyLink	96.33	98.96	99.39	322	90.9	53.7
Frontier (DSL)	93.69	98.18	<b>98.87</b>	553	160.0	98.7
Qwest	98.24	99.24	99.51	154	66.7	42.8
Verizon (DSL)	95.56	98.43	99.00	389	137.0	88.0
Windstream	94.35	98.72	99.42	495	112.0	50.6
<i>Wireless</i>						
Clearwire	88.95	96.96	<b>98.13</b>	968	266.0	164.0
<i>Satellite</i>						
Hughes	73.16	90.15	94.84	2350	863.0	453
Windblue/Viasat	72.27	84.20	96.37	2430	1380.0	318.0

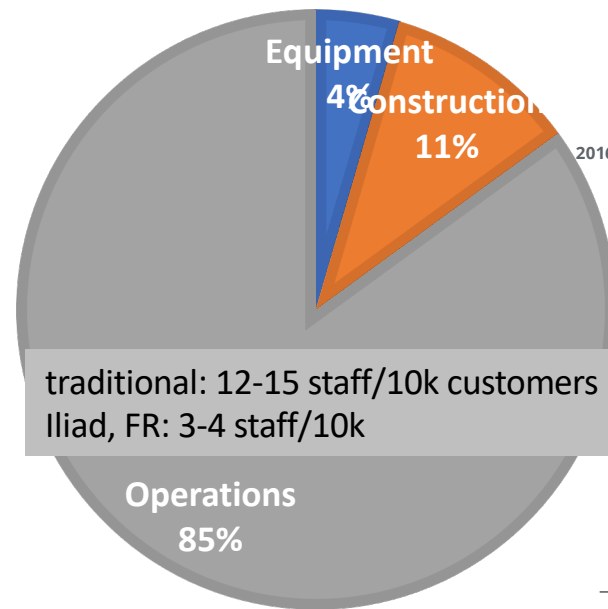




# Network economics, (over)simplified

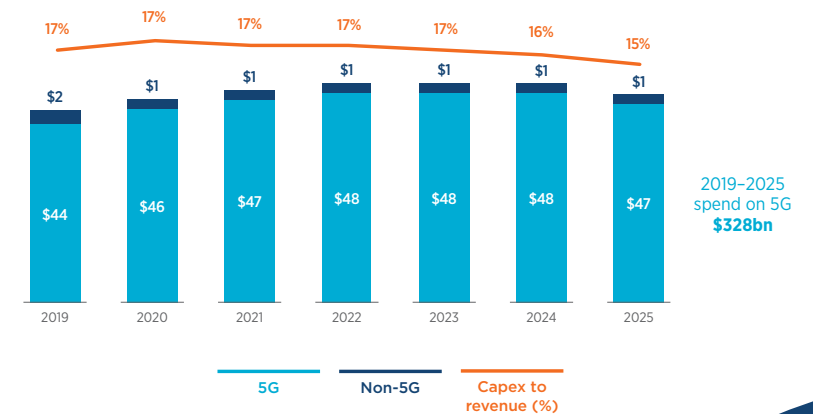
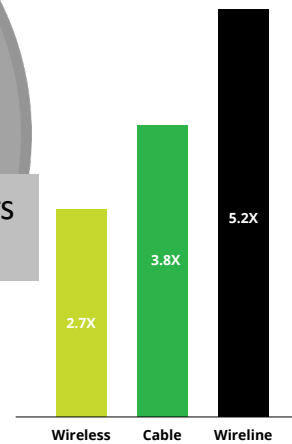
## % OF REVENUE

■ Equipment ■ Construction ■ Operations ■



traditional: 12-15 staff/10k customers  
Iliad, FR: 3-4 staff/10k

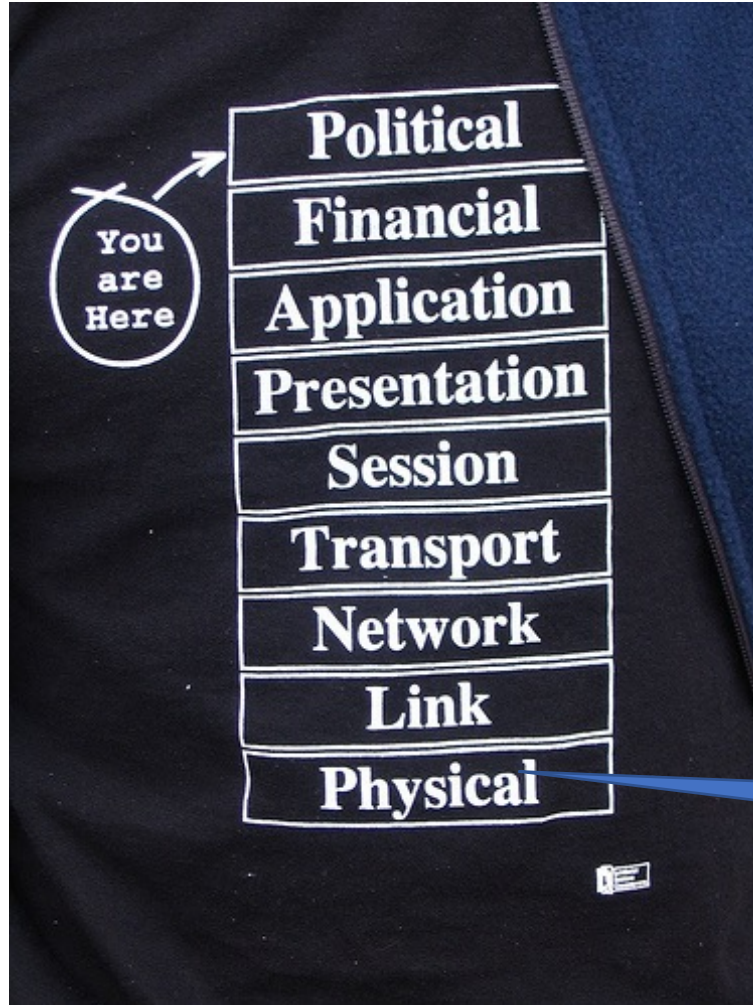
2016 Average OPEX to CAPEX ratios<sup>44</sup>



cellular

# Performance vs. cost

reliability



This is where the attention is

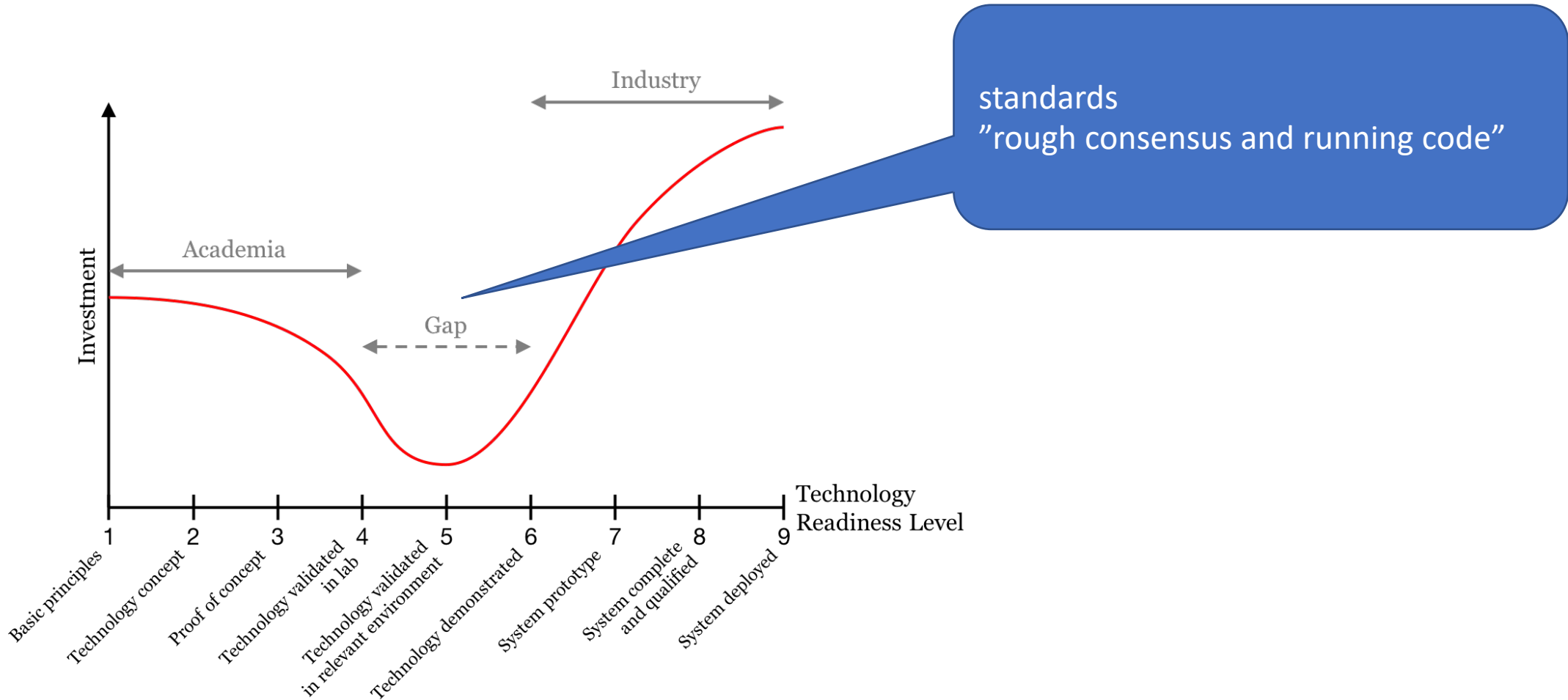
This is where the opex costs are

10x performance improvements

This is where the capex costs are

Like civil engineers, we rely on standards  
or: implementors (mostly) don't read papers, they read standards

# Standards bridge the valley of death

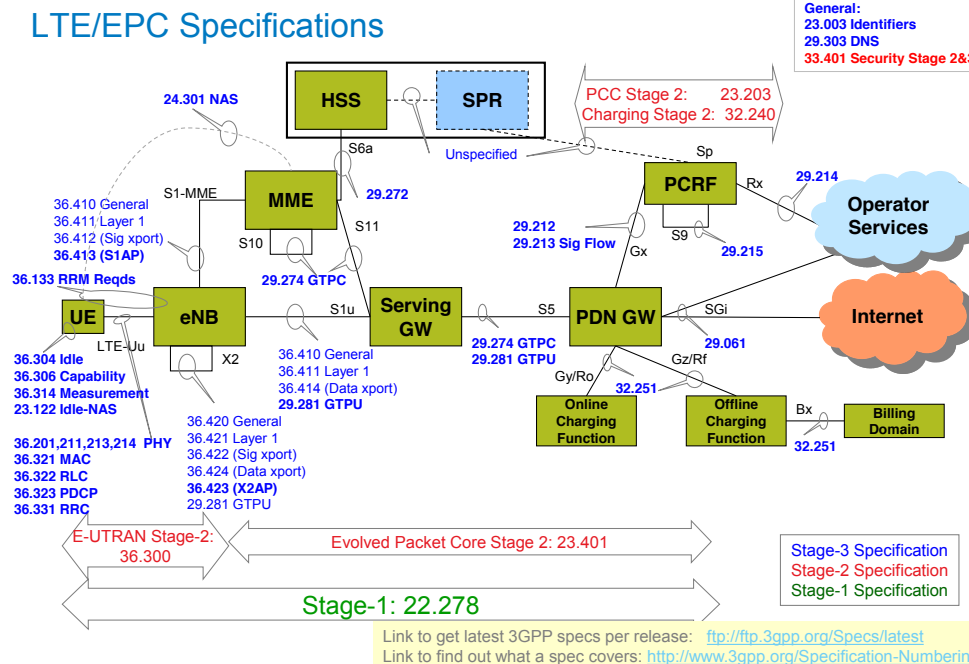


# Standards are eco-systems, not one document

What students see:

“SMTP, defined in RFC 5321, is at the heart of ... mail.” (Kurose/Ross)

What implementors see:



Irfan Ali

## Session Initiation Protocol (sip)

About Documents Meetings History Photos Email expansions List archive >

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Document ▾

**RFCs (75 hits)**

[RFC 2976](#) (was draft-ietf-sip-info-method)  
The SIP INFO Method

[RFC 3204](#) (was draft-ietf-sip-isp-mime)  
MIME media types for ISUP and QSIG Objects

[RFC 3261](#) (was draft-ietf-sip-rfc2543bis)  
SIP: Session Initiation Protocol

[RFC 3262](#) (was draft-ietf-sip-100rel)  
Reliability of Provisional Responses in Session Initiation Protocol (SIP)

[RFC 3263](#) (was draft-ietf-sip-srv)  
Session Initiation Protocol (SIP): Locating SIP Servers

[RFC 3265](#) (was draft-ietf-sip-events)  
Session Initiation Protocol (SIP)-Specific Event Notification

[RFC 3310](#) (was draft-ietf-sip-digest-aka)  
Hypertext Transfer Protocol (HTTP) Digest Authentication Using Authentication and Key Agreement (AKA)

[RFC 3311](#) (was draft-ietf-sip-update)  
The Session Initiation Protocol (SIP) UPDATE Method

[RFC 3312](#) (was draft-ietf-sip-manyfolks-resource)  
Integration of Resource Management and Session Initiation Protocol (SIP)

[RFC 3313](#) (was draft-ietf-sip-call-auth)  
Private Session Initiation Protocol (SIP) Extensions for Media Authorization

[RFC 3319](#) (was draft-ietf-sip-dhcpv6)  
Dynamic Host Configuration Protocol (DHCPv6) Options for Session Initiation Protocol (SIP) Servers

[RFC 3323](#) (was draft-ietf-sip-privacy-general)  
A Privacy Mechanism for the Session Initiation Protocol (SIP)

[RFC 3325](#) (was draft-ietf-sip-asserted-identity)  
Private Extensions to the Session Initiation Protocol (SIP) for Asserted Identity within Trusted Networks

[RFC 3326](#) (was draft-ietf-sip-reason)  
The Reason Header Field for the Session Initiation Protocol (SIP)

[RFC 3327](#) (was draft-willis-sip-path)  
Session Initiation Protocol (SIP) Extension Header Field for Registering Non-Adjacent Contacts

[RFC 3329](#) (was draft-ietf-sip-sec-agree)  
Security Mechanism Agreement for the Session Initiation Protocol (SIP)

[RFC 3361](#) (was draft-ietf-sip-dhcp)  
Dynamic Host Configuration Protocol (DHCP-for-IPv4) Option for Session Initiation Protocol (SIP) Servers

[RFC 3420](#) (was draft-ietf-sip-sipfrag)  
Internet Media Type message/sipfrag

[RFC 3428](#) (was draft-ietf-sip-message)  
Session Initiation Protocol (SIP) Extension for Instant Messaging

[RFC 3486](#) (was draft-ietf-sip-compression)  
Compressing the Session Initiation Protocol (SIP)

[RFC 3515](#) (was draft-ietf-sip-refer)  
The Session Initiation Protocol (SIP) Refer Method

[RFC 3581](#) (was draft-ietf-sip-symmetric-response)  
An Extension to the Session Initiation Protocol (SIP) for Symmetric Response Routing

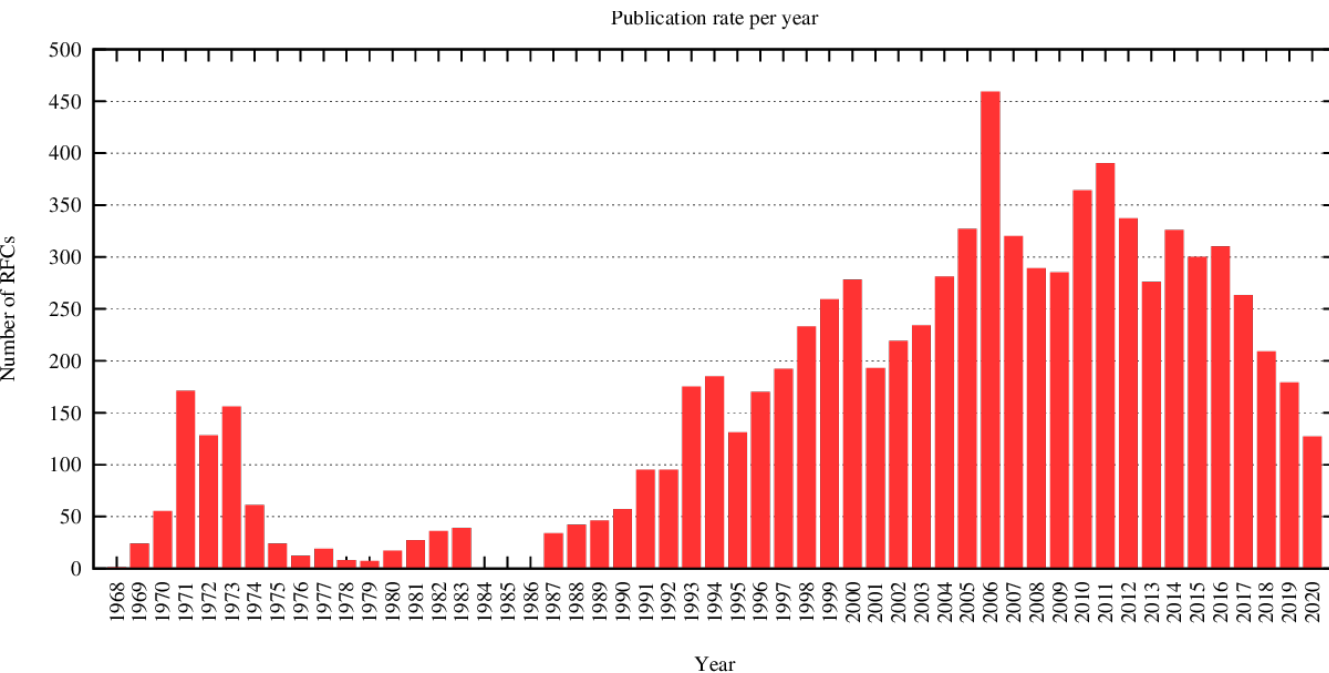
[RFC 3608](#) (was draft-ietf-sip-scvrtdisco)  
Session Initiation Protocol (SIP) Extension Header Field for Service Route Discovery During Registration

[RFC 3840](#) (was draft-ietf-sip-callee-caps)  
Indicating User Agent Capabilities in the Session Initiation Protocol (SIP)

[RFC 3841](#) (was draft-ietf-sip-callerprefs)  
Caller Preferences for the Session Initiation Protocol (SIP)

[RFC 3853](#) (was draft-ietf-sip-smime-aes)  
S/MIME Advanced Encryption Standard (AES) Requirement for the Session Initiation Protocol (SIP)

# Network standards are becoming less & more important



- "good enough" + eco system
- only one company can change L4
- easy downloads on four platforms + web make proprietary applications preferable → sustainable recurring-fee business model

TECHTANK

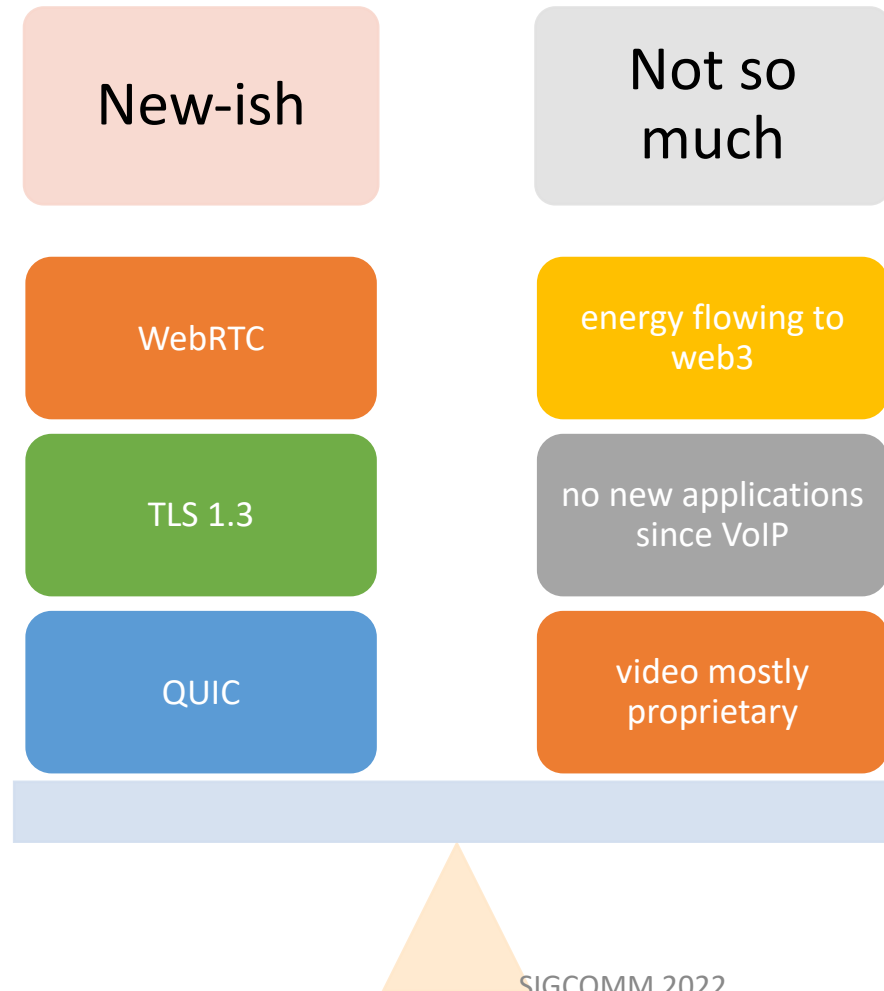
## The most important election you never heard of

Tom Wheeler · Friday, August 12, 2022

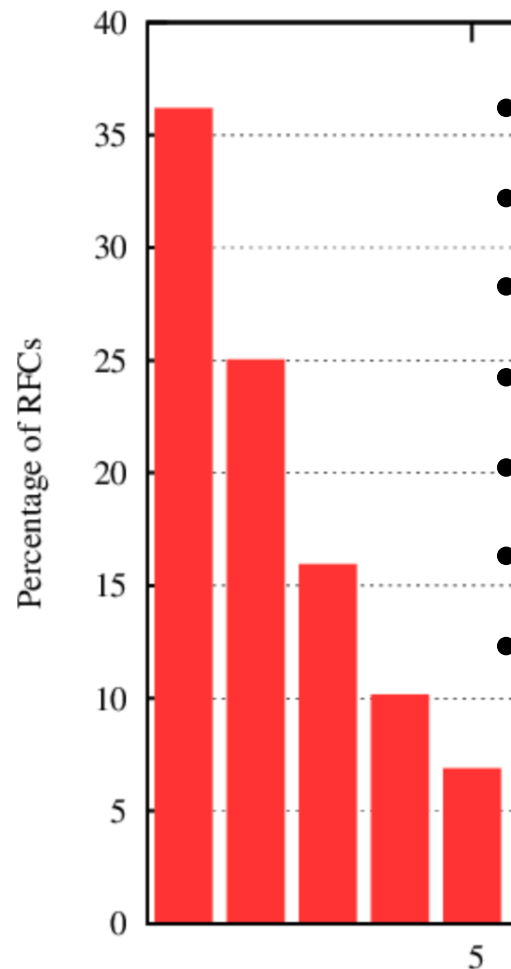
called "internet protocol" or "IP." China has proposed a new standard — called "New IP" — that would give governments more control over internet activities, including the individualized determination of who gets on and what they can do. They want that standard to be driven by the ITU.

The ITU has 193 voting member nations. The most important election no one has ever heard of for the most important network of the 21st century will be by secret ballot.

# Standards are (maybe) still important



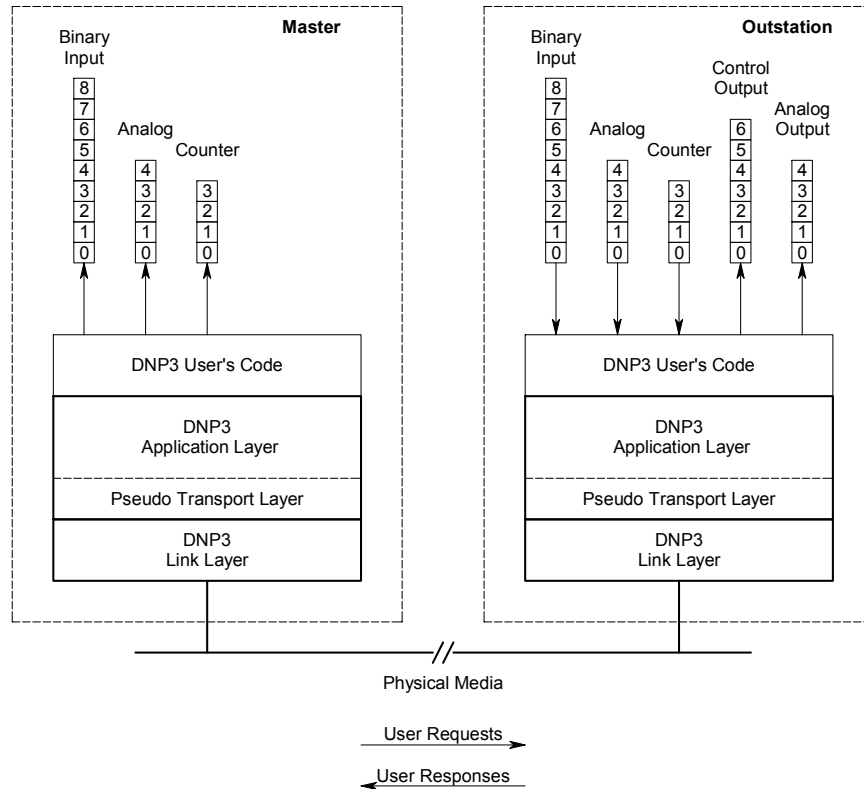
# IETF still has a reasonable bar to entry



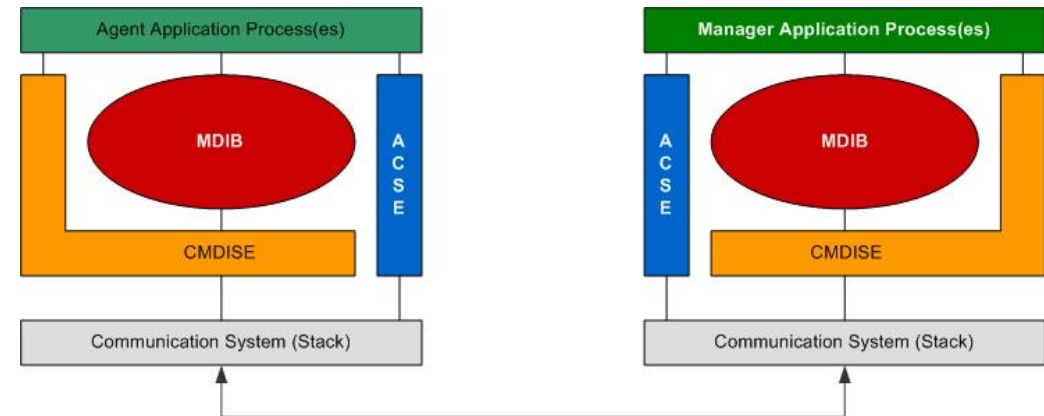
- Most efforts start small – being a graduate student is ok
- Last IETF: 5% of on-site, 8% of online participants academic
- Online participation (meeting & lists) lowers bar
- Get feedback on ideas
- IETF remains good option, but impact uncertain
- 2 approaches: small improvement or new area
- If you're really successful, nobody will cite you (any more)



# Networks typically beyond our radar (and opportunities for making them better)



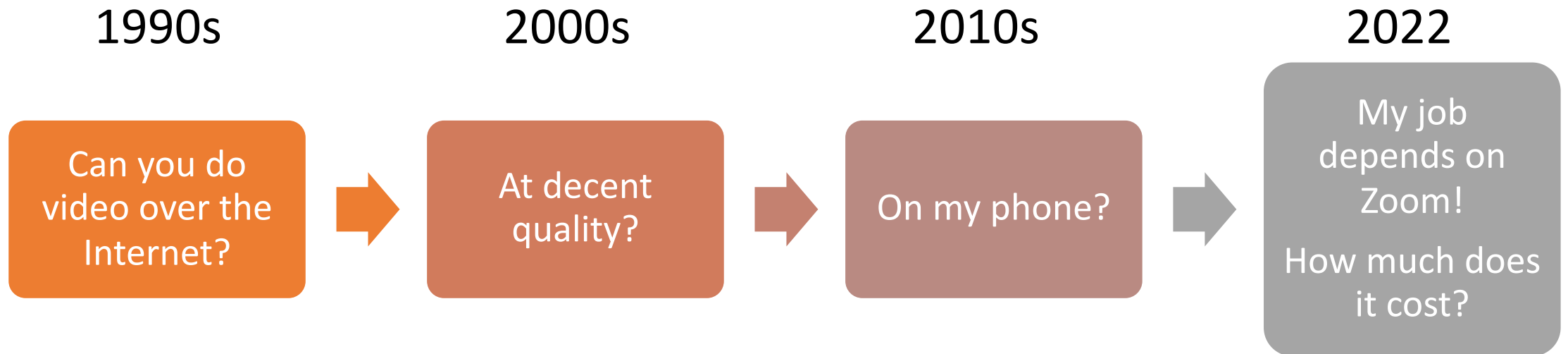
DNP3 (electric utilities)



IEEE 11073 (medical)

We are no longer the young  
crowd

# Evolution of networking



August 1993

~30 years ago



<b>Display</b>	4.5 in x 1.4 in (114 mm x 36 mm), 160 x 293 pixel CGA monochrome backlit LCD
<b>Connectivity</b>	2400-bps Hayes-compatible modem 33-pin connector 9600-bps Group 3 send-and-receive fax

IBM Simon (announced 11/1993)

Mosaic 1.0: November 1993

- Euro-ISDN: 1994
- DSL patent: 1990
- DOCSIS started 1995
- DSL in Germany: 7/1999



View on Wed Jun 4 09:30:20 MET DST 1997 (Wed Jun 4 07:30:20 GMT 1997) from office on the 4th floor onto the main Berlin railroad station Berlin Zoologischer Garten, with the fardenbergplatz bus terminal in front. (Berlin weather). A full-size (90 kByte) version and a legend are also here. During the day, lots of trains arrive and depart. A Day in the Life of Zoo Station -- 4 hours as an MPEG movie (about 2 Mbytes; contains P and B frames).

GMD webcam (1997)



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# IETF25 (1992) looks familiar

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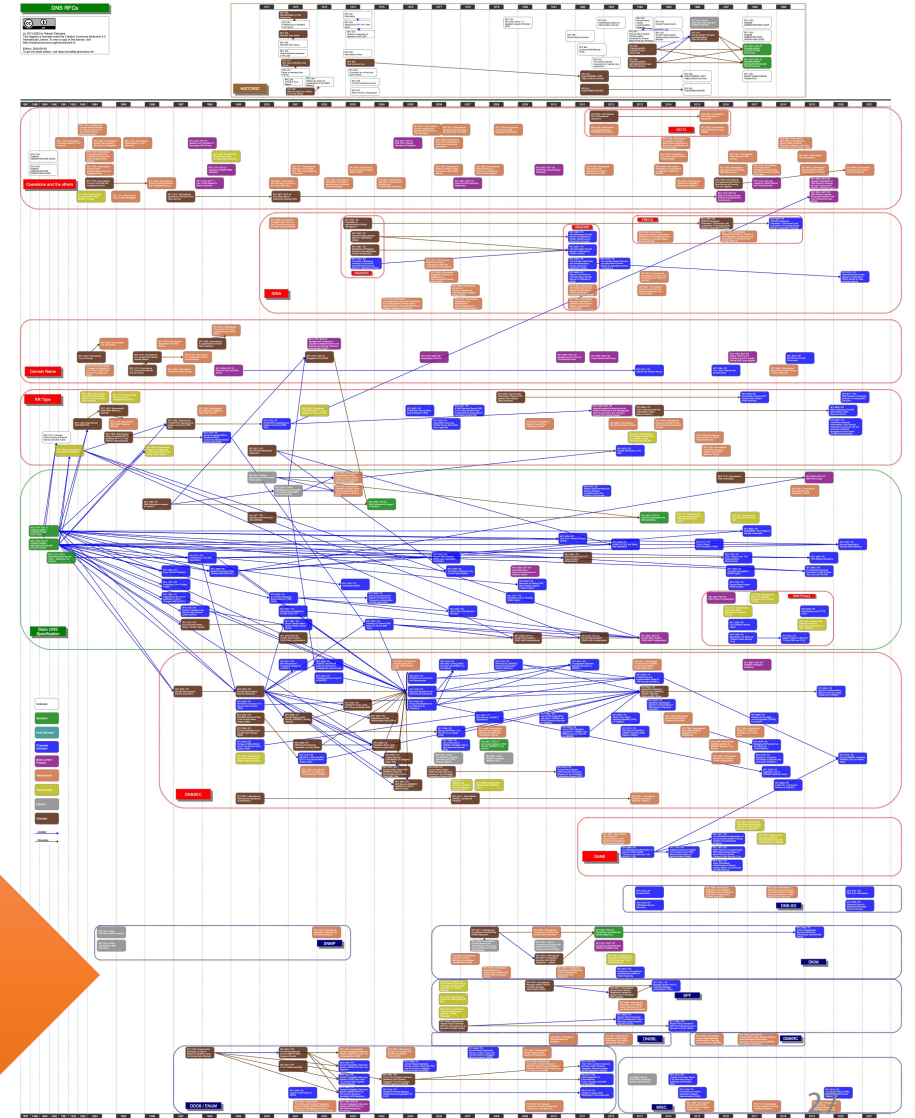
# We've met complexity, and it is us



“In fact, the code complexity of an IP router now rivals that of a 5ESS telephony switch [app. 5-10 million lines of code].”  
(Ramjee, 2016)

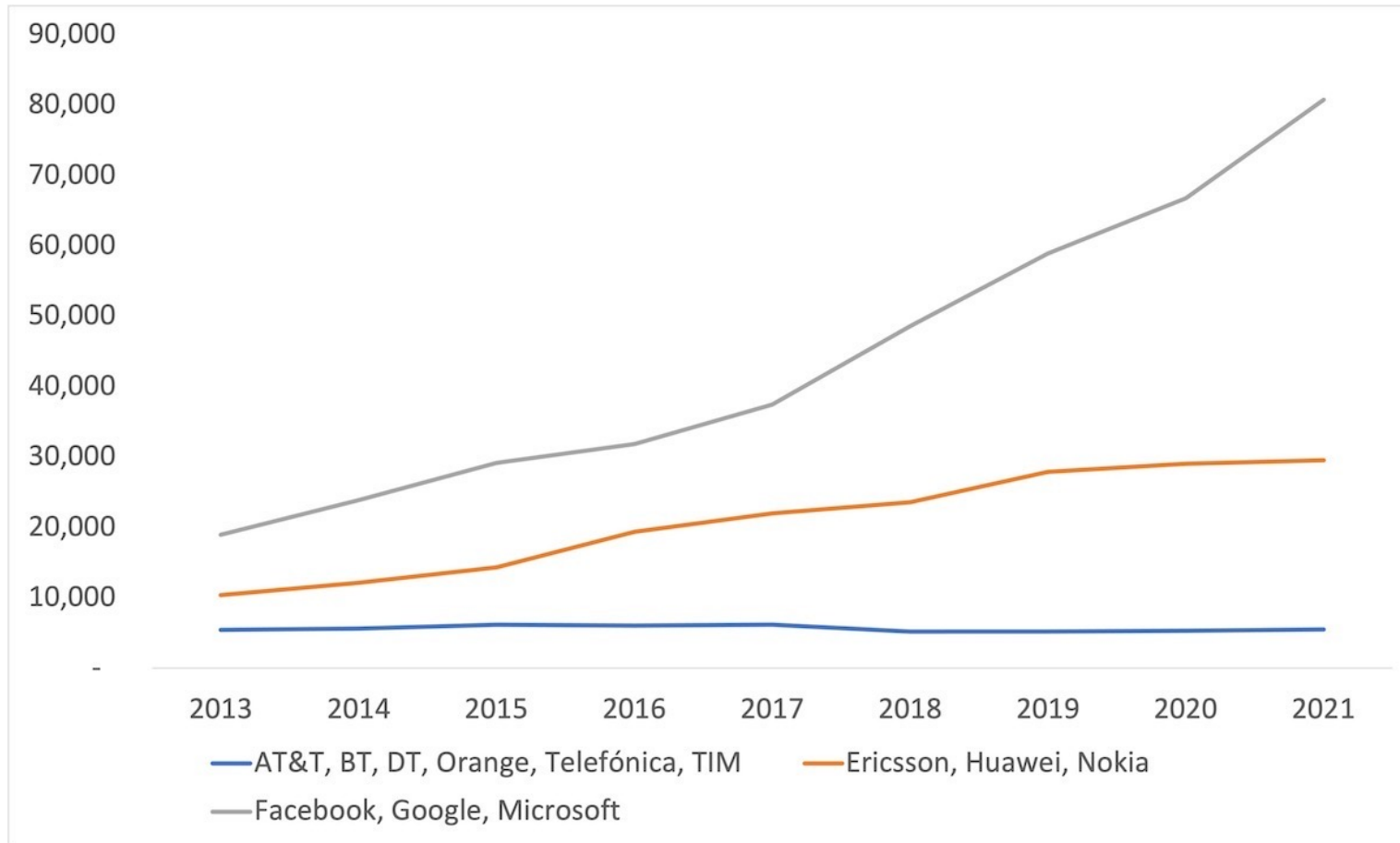
Quagga: 226,048 CLOC

RFC 1034: 54  
pages (1987)



# Carriers no longer doing research

R&D spending (\$M)



	R&D (2021)	total
AT&T	0.84%	
BT	0.29%	2.9%
DT	0.03%	0.59%
Orange	1.46%	
Ericsson	18.1%	
Huawei	22.40%	
Nokia	18.98%	
Facebook	20.95%	
Google	12.25%	
Microsoft	12.36%	



With impact comes responsibility

# “100% of robocalls use the protocol I worked on”

too cheap to meter  
the death of distance  
unregulated (not PSTN)  
open-source software  
programmable  
low barriers to entry

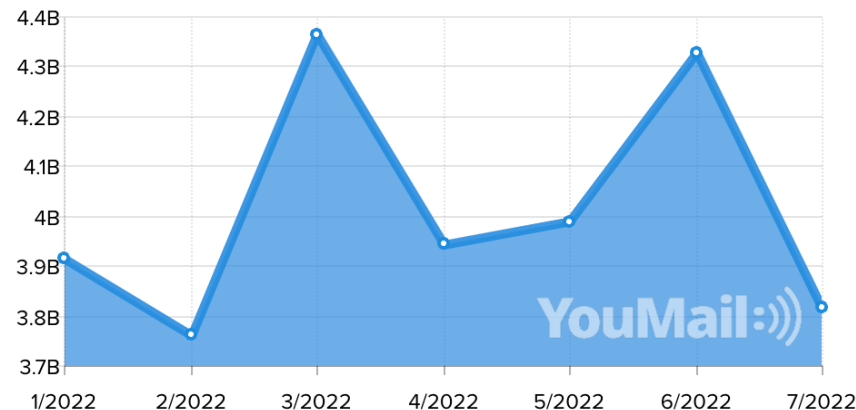
## 2022 Robocall Impact

CALLS PLACED

**28.1B**

AVG. CALLS PER PERSON

**85.7**



### Technology

- STIR/SHAKEN
- Traceback
- Analytics

### Law & regulation

- TRACED Act
- Mandate caller auth.
- Robocall Mitigation DB

### Operations

- Traceback
- KYC

### Law enforcement

- State AGs

incremental, not done yet!

# The good, the bad & the ugly – we can't just take credit for the first

## The good

### Telehealth Has Played an Outsized Role Meeting Mental Health Needs During the COVID-19 Pandemic

Justin Lo, Matthew Rae, Krutika Amin, Cynthia Cox, Nirmita Panchal, and others  
Published: Mar 15, 2022



WIKIPEDIA  
The Free Encyclopedia



## Bad but improvable

unwanted communications  
DDOS  
CIA violations

➔ bad actors are the “other”

lack of reliability  
lack of usability

## Wicked problems

We've met the problem – and they sponsor our conferences and hire our students!

WHY THE PAST 10 YEARS OF AMERICAN LIFE HAVE BEEN UNIQUELY STUPID

**Opinion** | How social media has undermined our constitutional architecture

deindustrialization  
death of Main Street

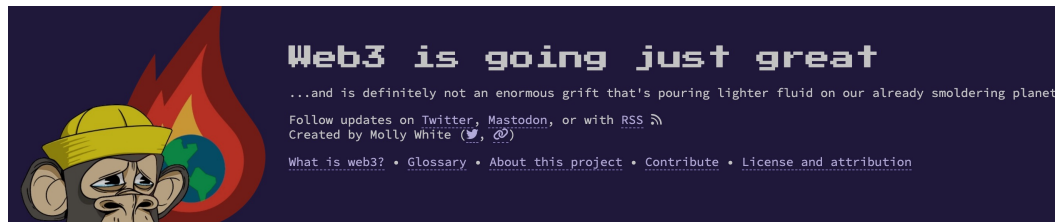
# What if you build a technology and nobody (except VCs) want it?

V2-WHO? NEVER HEARD OF IT, MATE. —

## Court rules FCC is allowed to reassign 5.9 GHz bandwidth, killing V2X

Bandwidth was set aside in 1999, but V2X has been an abject failure.

JONATHAN M. GITLIN - 8/16/2022, 11:15 AM



If Sidewalk's Quayside failure taught us anything, it's that these technologies need to respond better to human needs. Sure, the tech industry has made life more productive over the past two decades, but has it made it better?

“We’re just designing concrete structures”



## How Interstate Highways Gutted Communities—and Reinforced Segregation

America's interstate highway system cut through the heart of dozens of urban neighborhoods.

FARRELL EVANS • OCT 20, 2021

*"Once the rockets are up,  
who cares where they come down?  
That's not my department,"  
says Wernher von Braun. (Tom Lehrer)*

# But we're just building tools!

The but-for test is a test commonly used in both [tort law](#) and [criminal law](#) to determine [actual causation](#). The test asks, "*but for the existence of X, would Y have occurred?*" (Cornell LII)

The internet is not just the telephone network with packets

- any (digital) content
- ubiquity in time & space
- amplification: one-to-many & any-to-one
- generality
- programmability & automation
- international

# Individualized ethics falls short

*ACM Code of Ethics:* "Computing professionals should consider whether the results of their efforts will respect diversity, will be used in socially responsible ways, will meet social needs, and will be broadly accessible. They are encouraged to actively contribute to society by engaging in pro bono or volunteer work that benefits the public good."

Test your ML system for bias.  
Use encryption in your protocols.  
Make systems accessible.

- Unbiased ML for content recommendation does not protect democracy.
- Encryption does not mean privacy.
- Accessible systems may not mean inclusion.

## How Useful Is Recycling, Really?

Among all possible climate actions, recycling ranks pretty low in its impact.

SIGCOMM 2022

"nerd harder"

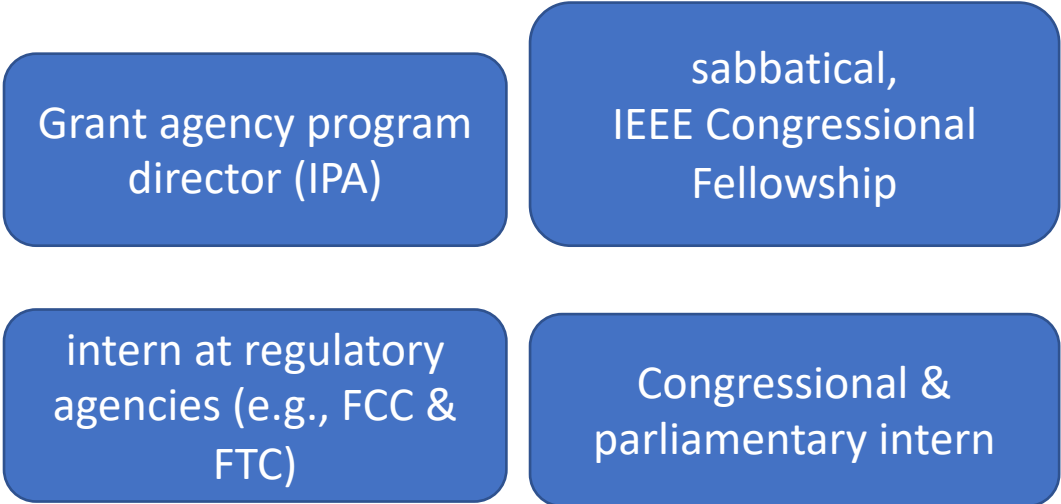


# Civil Engineering Ethics (ASCE) – [Society]

- “first and foremost, **protect the health, safety, and welfare of the public;**
- **enhance the quality of life for humanity;**
- express professional opinions truthfully and only when founded on adequate knowledge and honest conviction;
- endeavor to be of service in civic affairs;
- acknowledge the diverse historical, social, and cultural needs of the community, and incorporate these considerations in their work;
- **consider the capabilities, limitations, and implications** of current and emerging technologies when part of their work; and
- report misconduct to the appropriate authorities where necessary to protect the health, safety, and welfare of the public.”



# Don't (just) complain about how clueless the government is



April 18, 2022  
Ms. Marlene H. Dortch, Secretary  
Federal Communications Commission  
45 L Street, NE Washington, DC 20554  
**RE: Empowering Broadband Consumers Through Transparency, CG Docket No. 22-2**  
Dear Ms. Dortch:  
On Thursday, April 14th, 2022, Walter Johnston (Danu Consulting), Andreas Carlos Freund (Department of Computer Science, Columbia University<sup>1</sup>) and Henning Schulzrinne (Department of Computer Science, Columbia University) met virtually with five Commission staff members regarding matters in the above-referenced proceedings. The staff members present were Aaron Garza, Erica McMahon, Mika Savir, Mark Stone and Kristin Thornton, all from the Consumer and Governmental Affairs Bureau.

eha [Modify Search](#)

**Filings** 50 Results (451ms) [RSS](#)

5 10 25 50 100 **A** **A** **A** Date Posted: Descending

**Jon Peha** OET 22-137

Peha\_comment\_on\_receiver\_NOI\_June\_2022.pdf

Received: 06/27/2022 Posted: 06/27/2022 [COMMENT](#)

# Responsible AI → responsible networking

## Responsible AI practices

The development of AI is creating new opportunities to improve the lives of people around the world, from business to healthcare to education. It is also raising new questions about the best way to build fairness, interpretability, privacy, and security into these systems.

Google

Responsible AI ensures that AI and machine learning (ML) models *are Robust, Explainable, Ethical and Efficient.* (FICO)

Robust ✓  
Ethical ✓  
Abuse-resistant?  
Responsive to public policy?

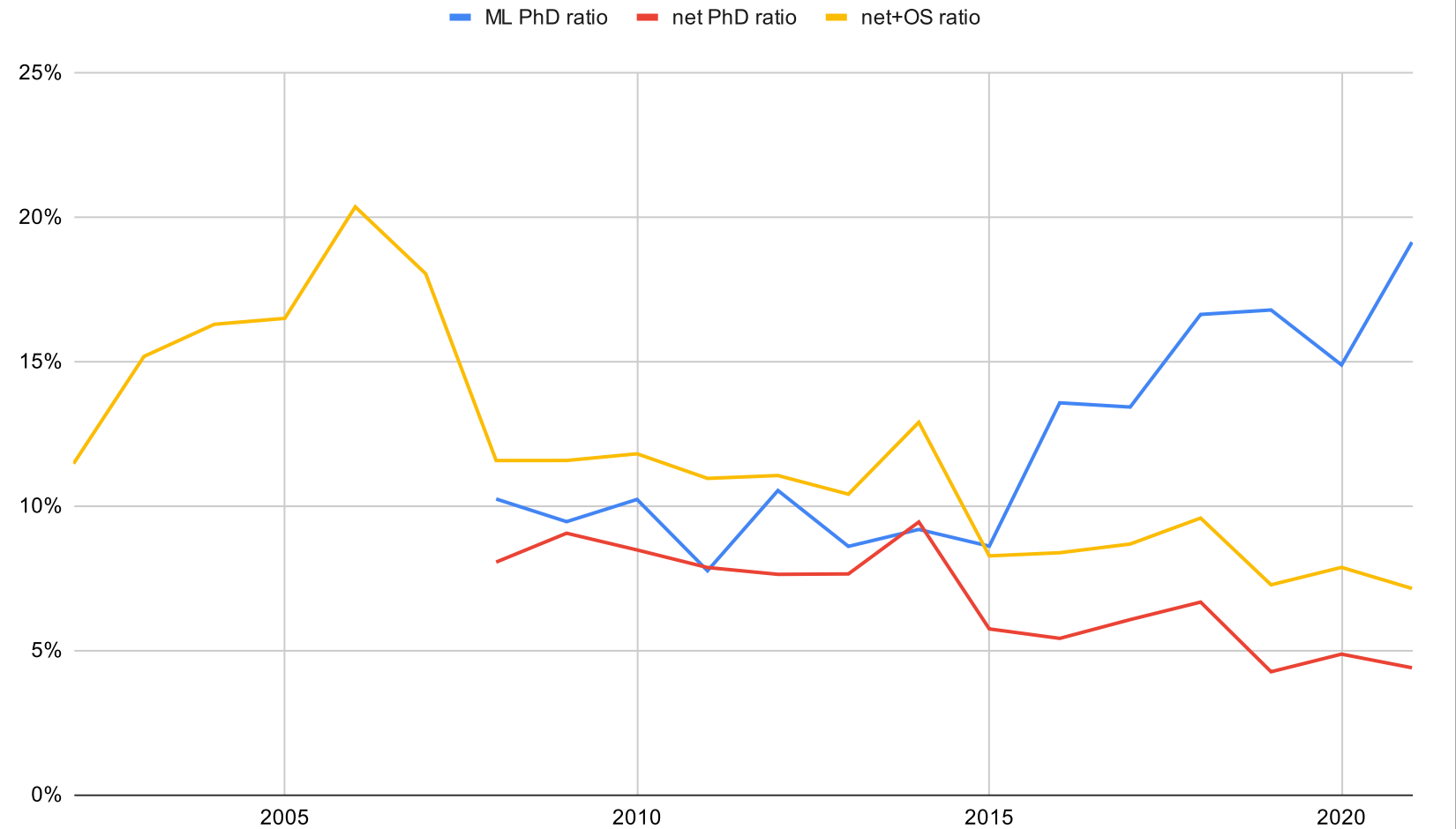
# The next generation network(ers)

# Networking: now dominated by ML

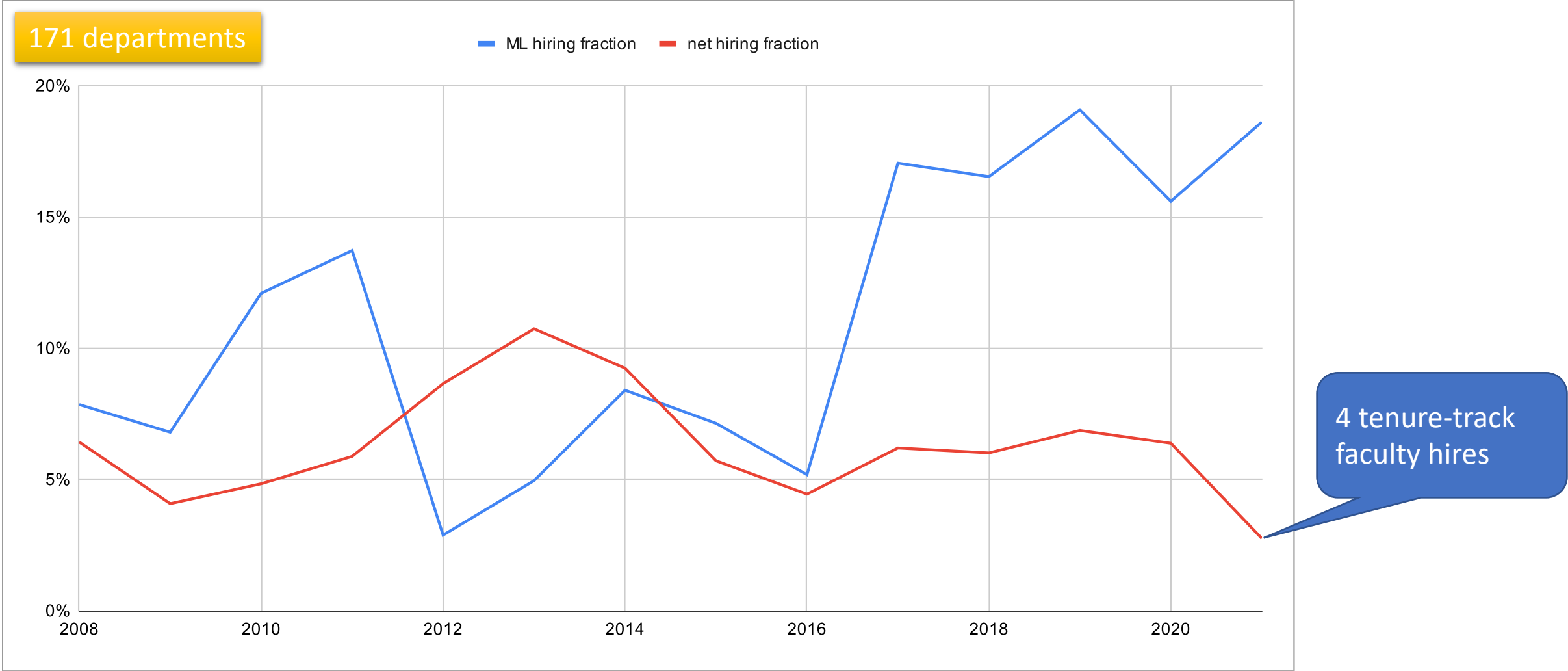
CRA Taulbee Surveys of PhD-granting CS & CE departments in US & Canada

Do we know why?

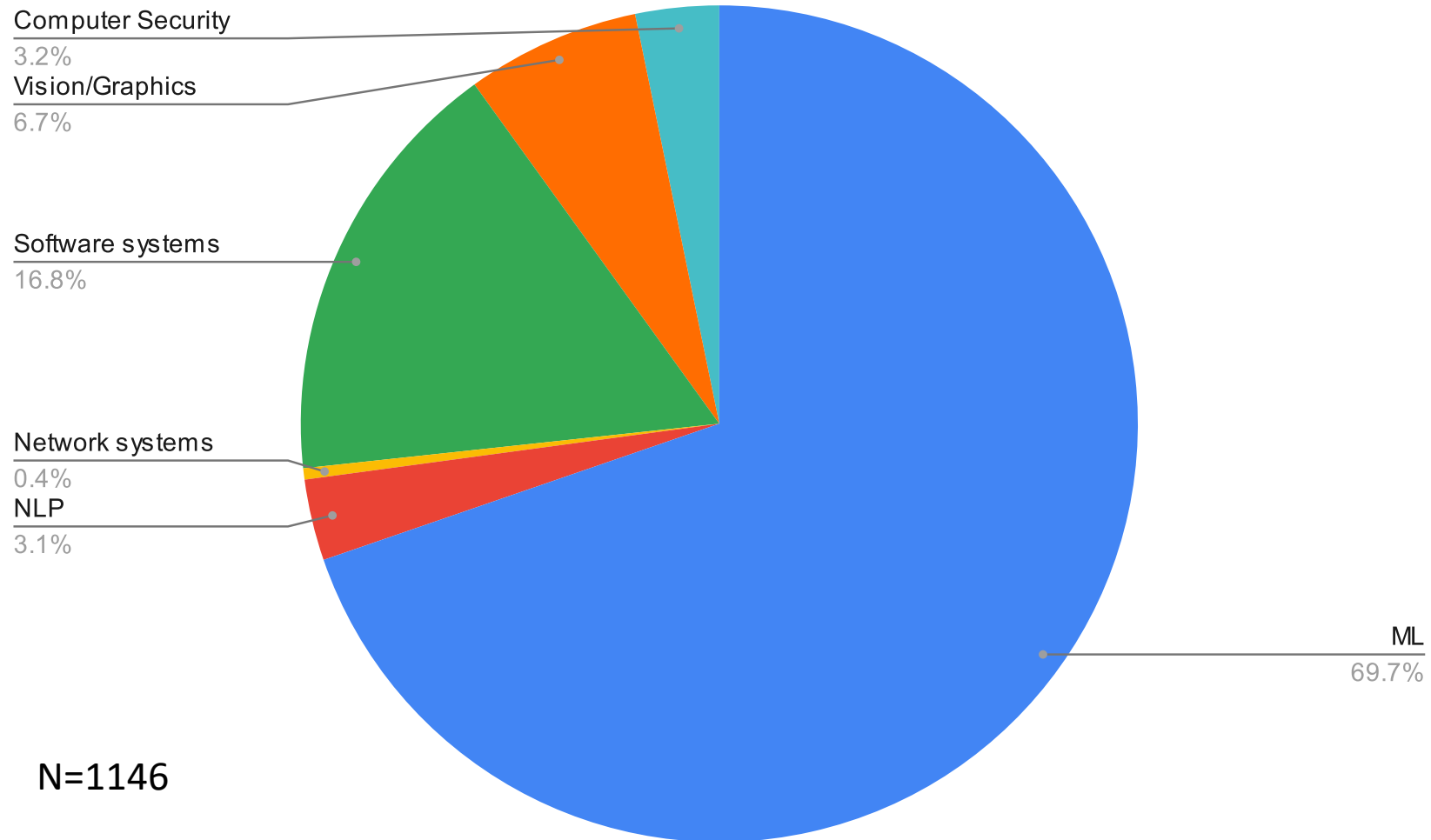
- “petroleum engineering”
- “booring”
- “no jobs”



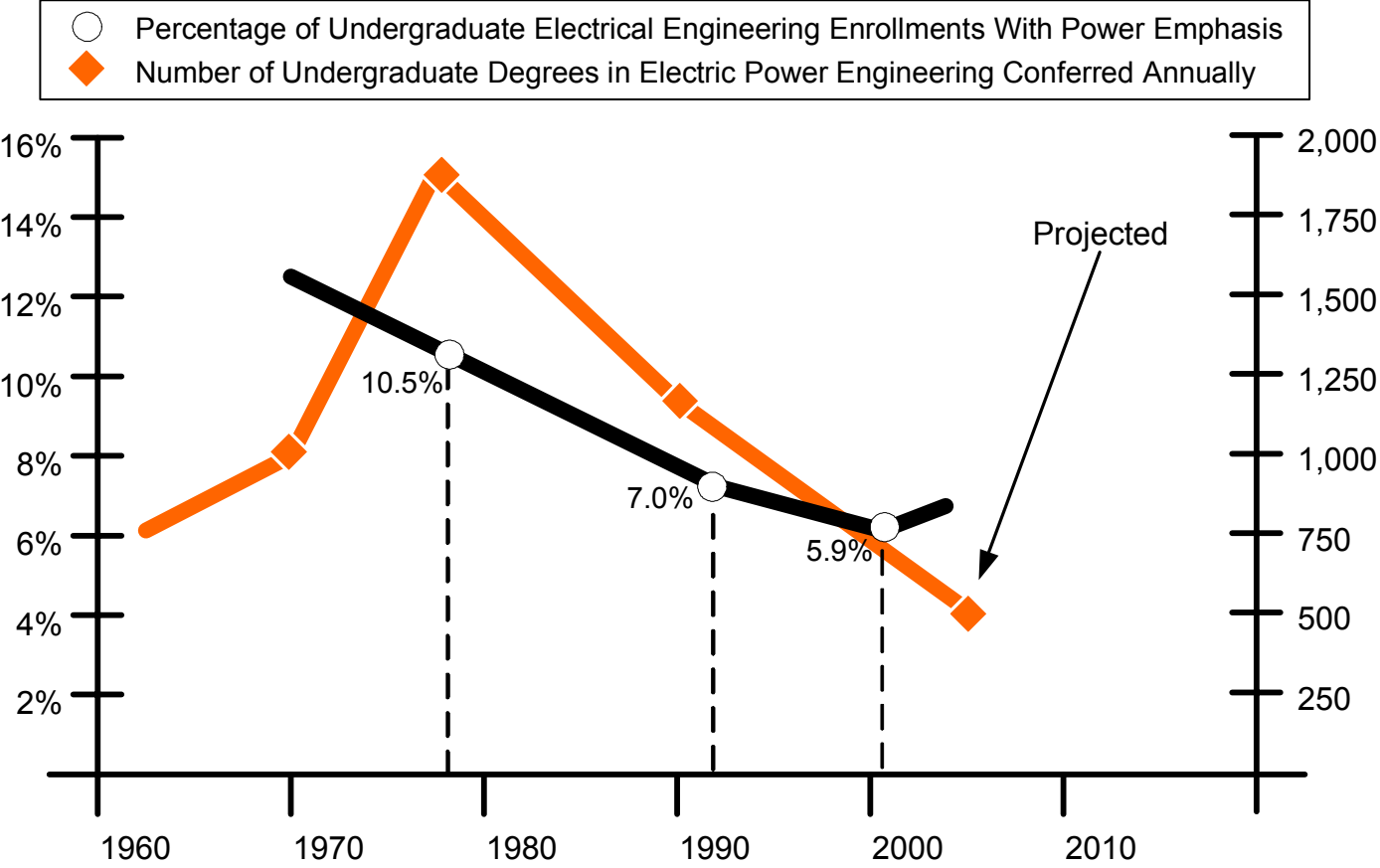
# The faculty pipeline is drying up



# 2022 Columbia University CS MS student tracks



# Infrastructure is not a hot subject



*Today's Power Engineering Shortage – An Alarming Problem With a Powerful Upside (2008)*

“77% of energy companies find it difficult to hire qualified employees.”

“There has been a decline in power engineering programs at universities over the past two decades; the current estimate is less than 30 programs in the United States and about 75 programs worldwide.” (2008)

Fig. 2. United States electrical engineering students with a power emphasis contrast with degrees conferred annually



Few(er) students may want to do networking research  
All\* students need to understand networks

- **Current:** how does congestion control work?
  - few students take the quad: OS, networks, distributed systems, security
- **Future:** how can I build scalable, reliable and secure services?
  - Do all CS students need to know how BGP and TCP Reno work?
- **Current:** digital & computer literacy
  - “the ability to use information and communication technologies to find, evaluate, create, and communicate information, requiring both cognitive and technical skills.”  
(ALA)
- **Future:** **internet literacy**
  - How does the internet function? Who governs that function? Who can change it?
  - How does digital advertising work?
  - What is privacy? Is it the same as encryption?
  - What are platforms? What is common carriage? What is Section 230?

[\[Syllabus and schedule\]](#) [\[Slides\]](#) [\[Projects\]](#)

## Description

This course provides a broad overview of current technology, economics and policy challenges in communications, the internet and digital platforms, emphasizing the "why" and "how", as well as historical connections. The course will rely on primary materials (published papers, white papers, technical reports, laws and regulations) and draw heavily on the diverse experiences of the students in the class, whose active participation is expected.

The class will attempt to provide a broad international perspective, with special emphasis on the United States, Canada and Europe.

The instructor has served in roles at the Federal Communications Commission (FCC) and, this past academic year, as a Technology Fellow in the office of Senator Ron Wyden.

Topics will include:

- Economic foundations of the internet economy: advertising and communication industry
- Overview of Internet technology (how does the Internet work)
- Review of basic principles of micro-economics
- How does the law work?
- A bit of communication history
- The role of communication policy and regulation (Telecom Act, FCC overview)
- Common carriage, significant market power and other regulatory frameworks
- Platforms: definition, impact and regulation
- Protocol and architecture standardization
- The economics of networks and platforms (building networks, natural monopolies, ...)
- Wireless communications: from AM radio to cellular
- Spectrum: properties, allocation and co-existence
- Network neutrality and the Open Internet
- Peering, transit and traffic exchange
- Names, numbers and addresses
- Basic principles of network security
- Internet security challenges: "cybersecurity"
- Internet security challenges: unwanted communication
- Privacy and surveillance
- Content regulation
- Communication for all: enabling technologies for people with disabilities (relay services, accessibility, CVAA, ...)
- Internet governance: ICANN, ITU and other actors



# Thank you to my mentors



Lee Chegwidan  
MEG



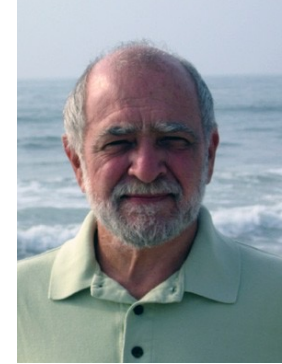
P.A. Ramamoorthy  
U Cincinnati



Howard Fan  
U Cincinnati



Weibo Gong  
UMass Amherst



Nick Maxemchuk  
AT&T Bell Labs



Adam Wolisz  
GMD/TU Berlin



Al Aho  
Columbia U.



Julie Knapp  
FCC



David Furth  
FCC



Evan Kwerel  
FCC



Chris Soghoian  
Sen. Wyden

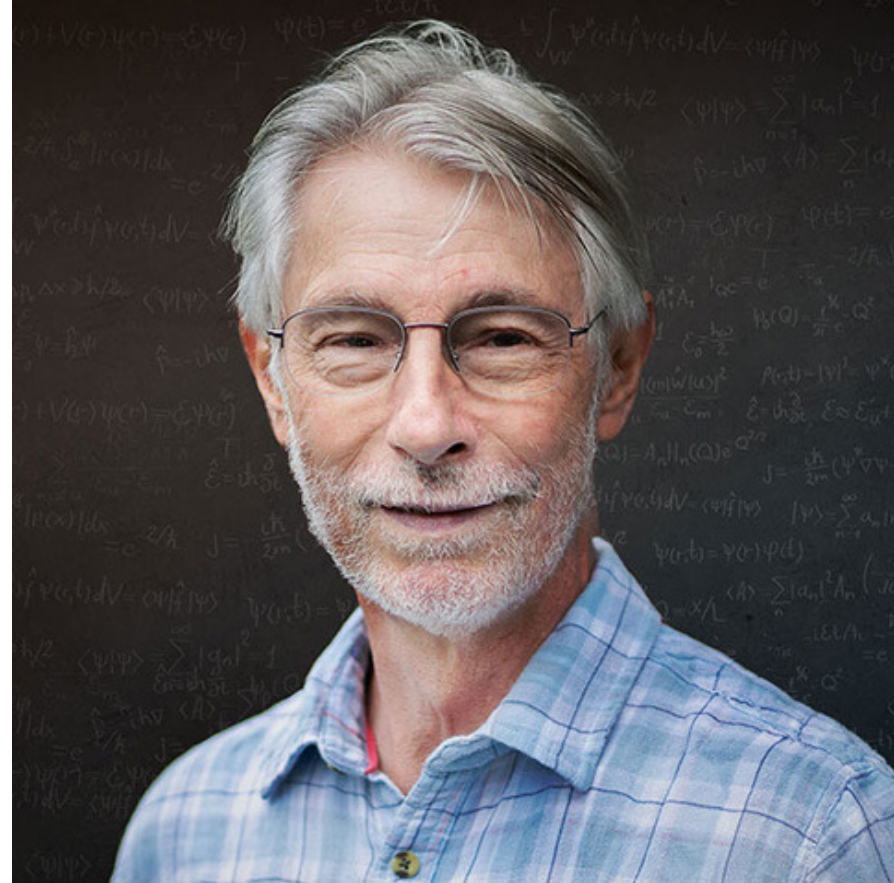


# And my academic “parents”



SIGCOMM 2016

8/24/22



SIGCOMM 2008

SIGCOMM 2022

# Students, collaborators and co-authors

Lisa Amini  
Karl Andersson  
Knarig Arabshian  
Artiom Baloian  
Jong Ho Bang  
Mary Barnes  
Salman A. Baset  
Victoria Beltran  
Stefan Berger  
Gregory Bond  
Omer Boyaci  
Piotr Boniss  
Jack Brassil  
Doru Calin  
Gonzalo Camarillo  
Steve Casner  
Haluk Celebi  
Dana Chee  
Prabhakar Chitrapu  
Maria Luiza Cristoforo

Ted Hardie  
Volker Hilt  
Se-Gi Hong  
Markus Isomaki  
Emil Ivov  
Van Jacobson  
Jan Janak  
Cullen Jennings  
Wenyu Jiang  
Alan Johnston  
Lukas Kaltenbach  
Dilip Kandlur  
Raimo Kantola  
Pekka Karhula  
Janet Kayfetz  
Wolfgang Kellerer  
Michael Kester  
Jong Yul Kim  
Kyung-Hwa Kim  
Timo Korkala

Archan Misra  
Vishal Misra  
Arezu Moghadam  
Edmundo Monteiro  
Marie Jose Montpetit  
Erich Nahum  
Vibhas V Naik  
Gautam Nair  
Hyunwoo Nam  
Ajay Nambi  
Sankaran Narayanan  
Alexander Nussbaum  
Florian Nussbaum  
Andrew Newton  
Hagen Odenhal  
Timo Ojala  
Kumiko Ono  
Gaston Ormazabal  
Joerg Ott  
Maria Benedekouli

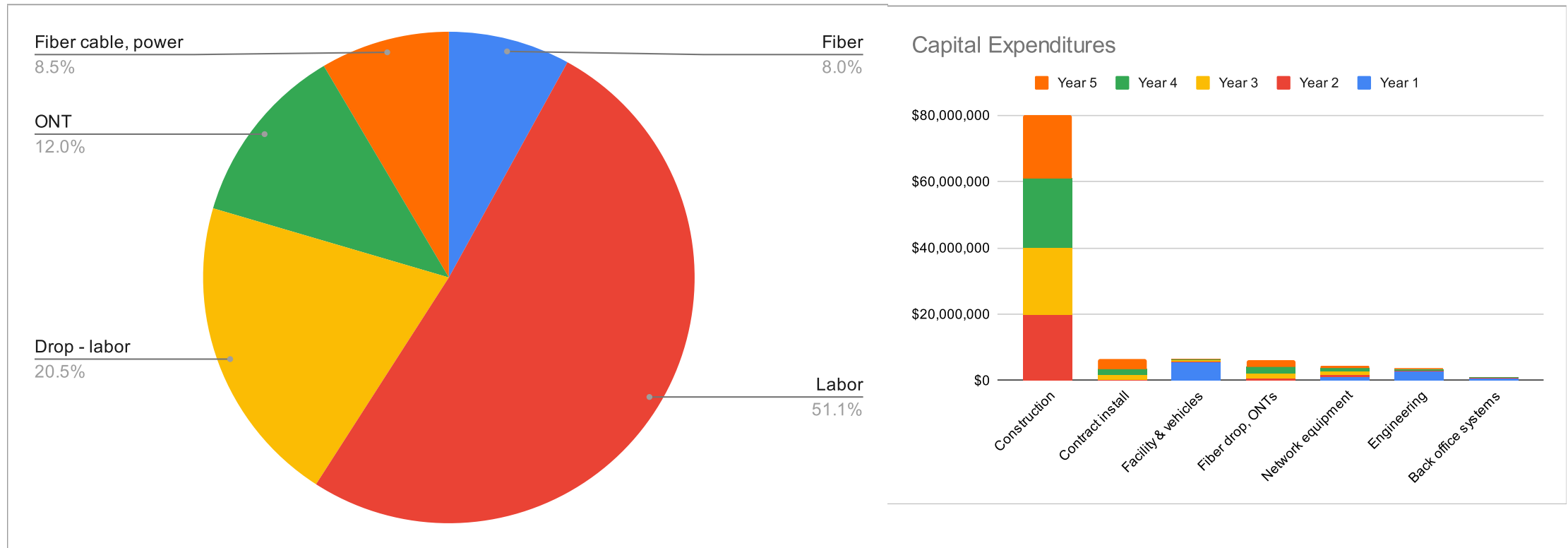
Sangho Shin  
Aman Singh  
Kundan Singh  
Vishal Singh  
Henry Sinnreich  
Dorgham Sisalem  
Wonsang Song  
Robert Sparks  
Suman Srinivasan  
Abhishek Srivastava  
Rolf Stadler  
Radu State  
Peter Steenkiste  
James Sterbenz  
Tom Taylor  
Srisakul Thakolsri  
Peter Thermos  
Don Towsley  
Dirk Trossen  
Hannes Tschafarzik

- A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a new generation grows up that is familiar with it ...

An important scientific innovation rarely makes its way by gradually winning over and converting its opponents: it rarely happens that Saul becomes Paul. What does happen is that its opponents gradually die out, and that the growing generation is familiarized with the ideas from the beginning: another instance of the fact that the future lies with the youth.

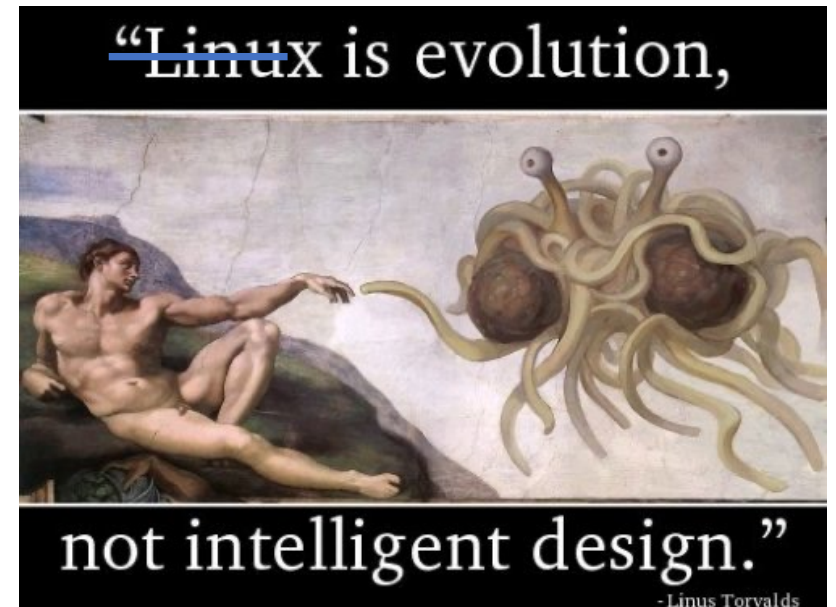
- — *Max Planck, Scientific autobiography, 1950, p. 33, 97*

# Example: Fort Collins, Colorado



Nobody beyond conference TPCs cares about the Internet because of its simplicity and mathematical elegance  
(and if you do, you may want to participate in recent standards meetings...)

The internet





# Or: network operators are like airlines (& beyond common carriage)

commodity  
(rarely loved, only hated less)

livery  
advertising  
pricing



Boeing 737  
designed 1967



INTERNET PROTOCOL

DARPA INTERNET PROGRAM

PROTOCOL SPECIFICATION

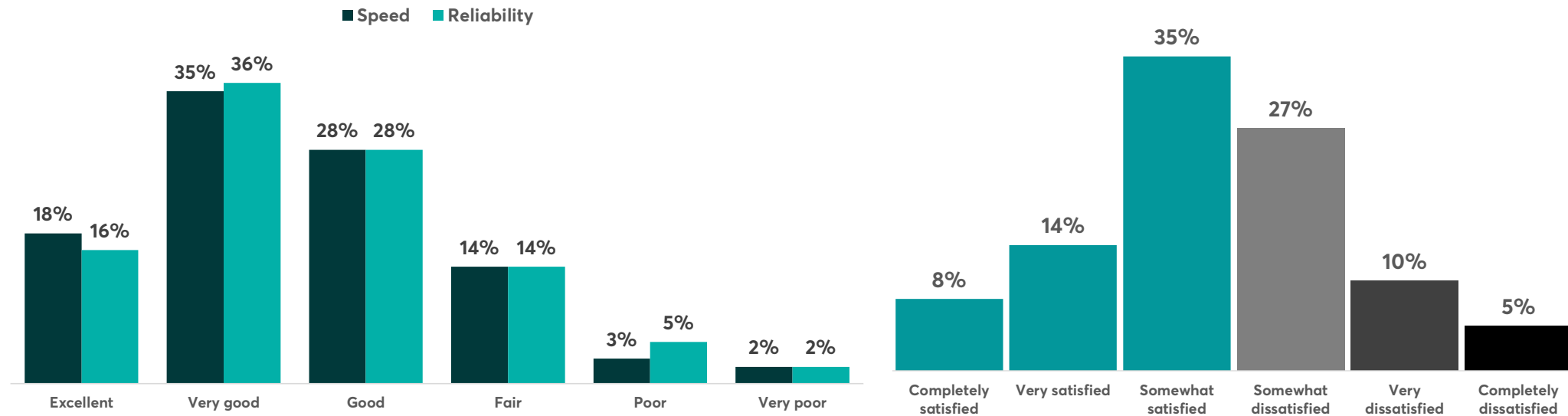
September 1981

SIGCOMM 2022



800 GSM operators

# Speed, reliability & price



*Consumer Reports, July 2021*

# My first research job



# Academic research vs. government

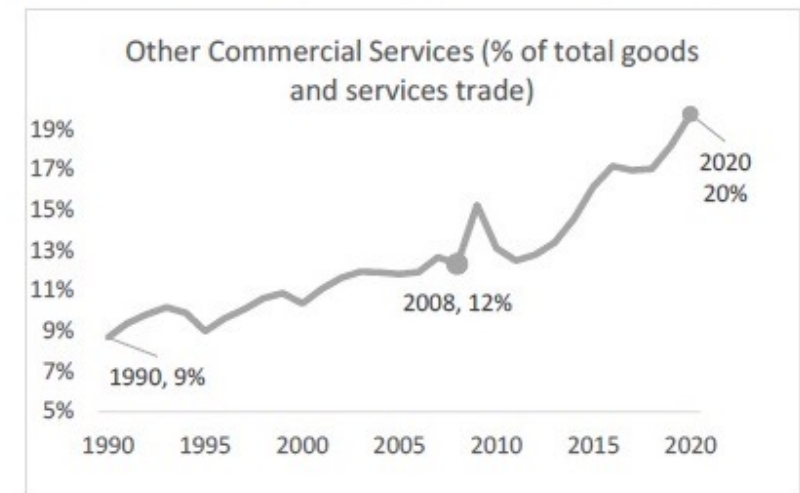
Academic research	Government work
Long deadlines (conference & PhD cycle)	Short deadlines – can be “today”, but can also take a year
Interdisciplinary in proposal; sub-discipline in paper	A lawyer, an economist and an engineer walk into a problem...
Self-motivate + PhD student	Small to large teams
Being novel – ok to assume	Being right, given real-world assumptions
Direction of effect	Magnitude of effect (does it matter?)
Convince conference committee	Convince non-specialists (lawyers, often)
Find a question you can answer well	Answer the question as well as you can
Become an expert on one topic (at a time)	Expected to know everything (“you’re an engineer”)
Explain to TPC and panel reviewers	Explain to generalists and the public
Find the optimal solution	Optimize within legal and political constraints
Your name appears on the paper	Usually, only the elected/appointed name appears

# Globotics & the next de-industrialization

1 <sup>st</sup> unbundling	lower cost of moving goods	19 <sup>th</sup> century – 1970s
2 <sup>nd</sup> unbundling	ICT coordination of manufacturing (off-shoring)	1990s
3 <sup>rd</sup> unbundling	Internet-based unbundling of services	now

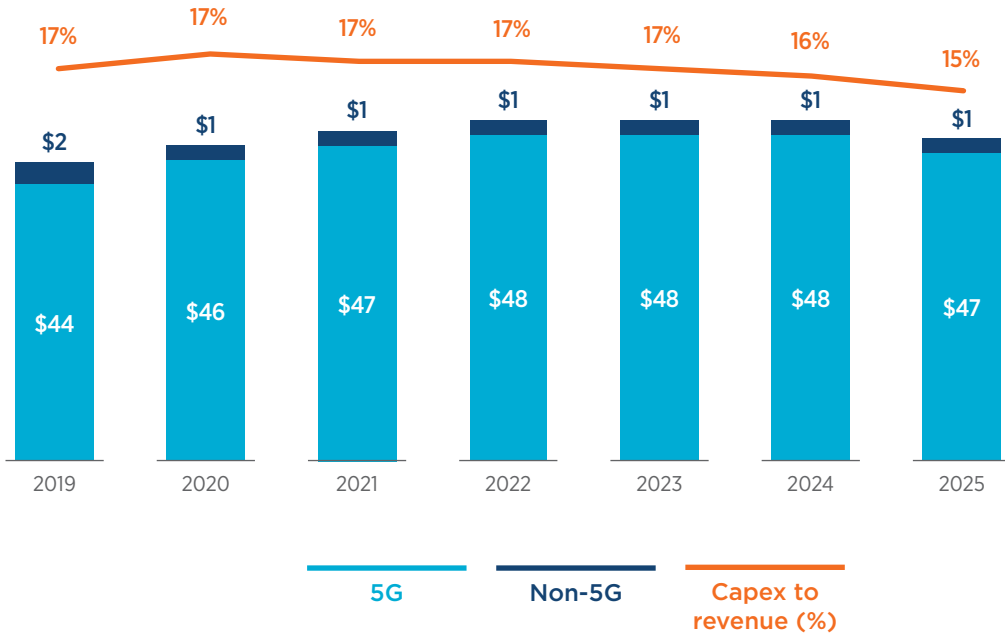
78% of US workers in service sector  
20% in industry

Trends in world trade in goods and services, 1990-2020





# We largely work on the ~15% part



2019-2025  
spend on 5G  
\$328bn

