

Networking: The Newest Civil Engineering Challenge

Henning Schulzrinne
(Columbia University)

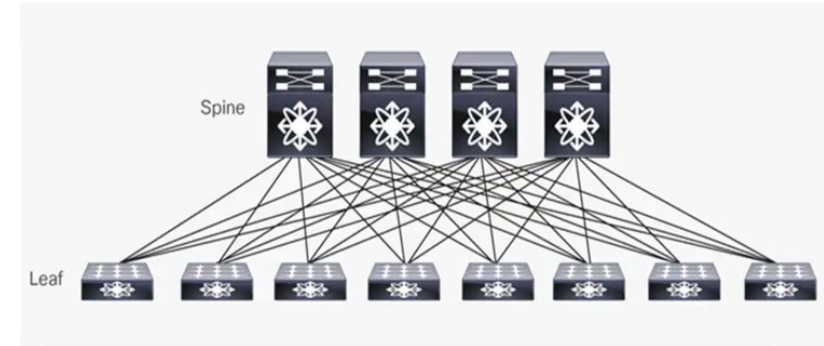
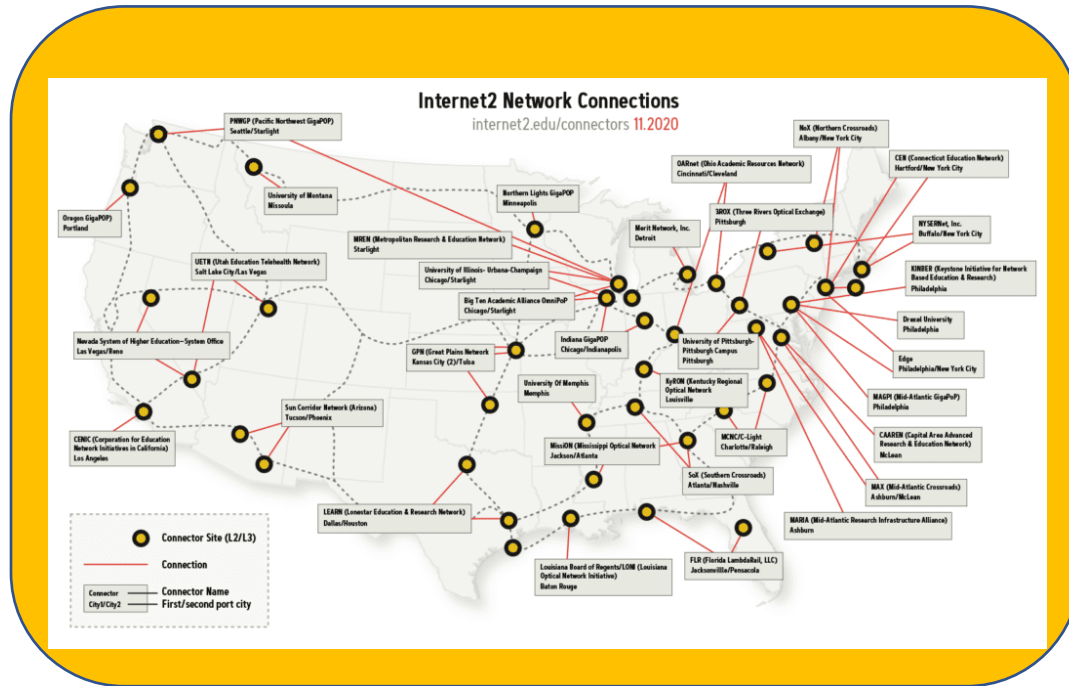
ICNP 2022

October 2022

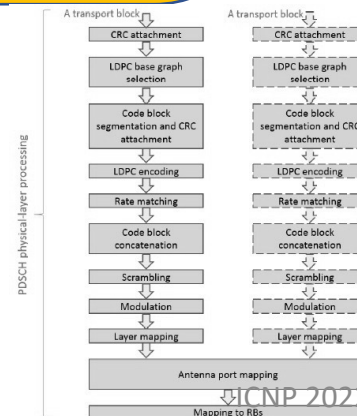
A retro-perspective into the future

- 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.

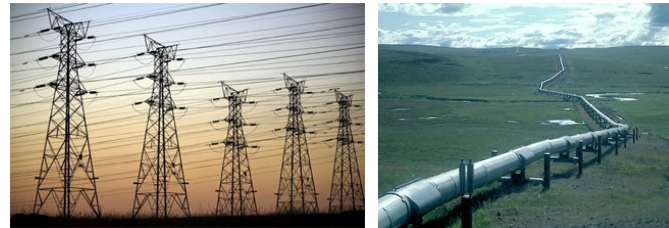
The great civil infrastructures

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

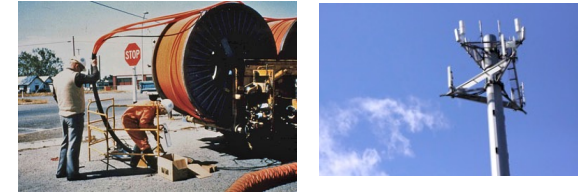
water



energy



internet communications



transportation



The Internet as core civil infrastructure

For Immediate Release

February 12, 2013

Executive Order -- Improving Critical Infrastructure Cybersecurity

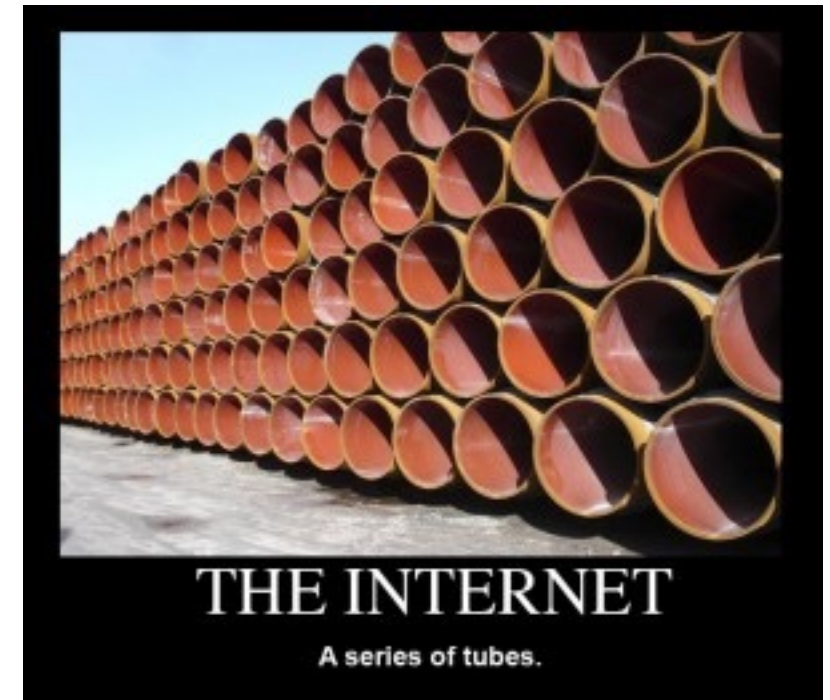
EXECUTIVE ORDER

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:

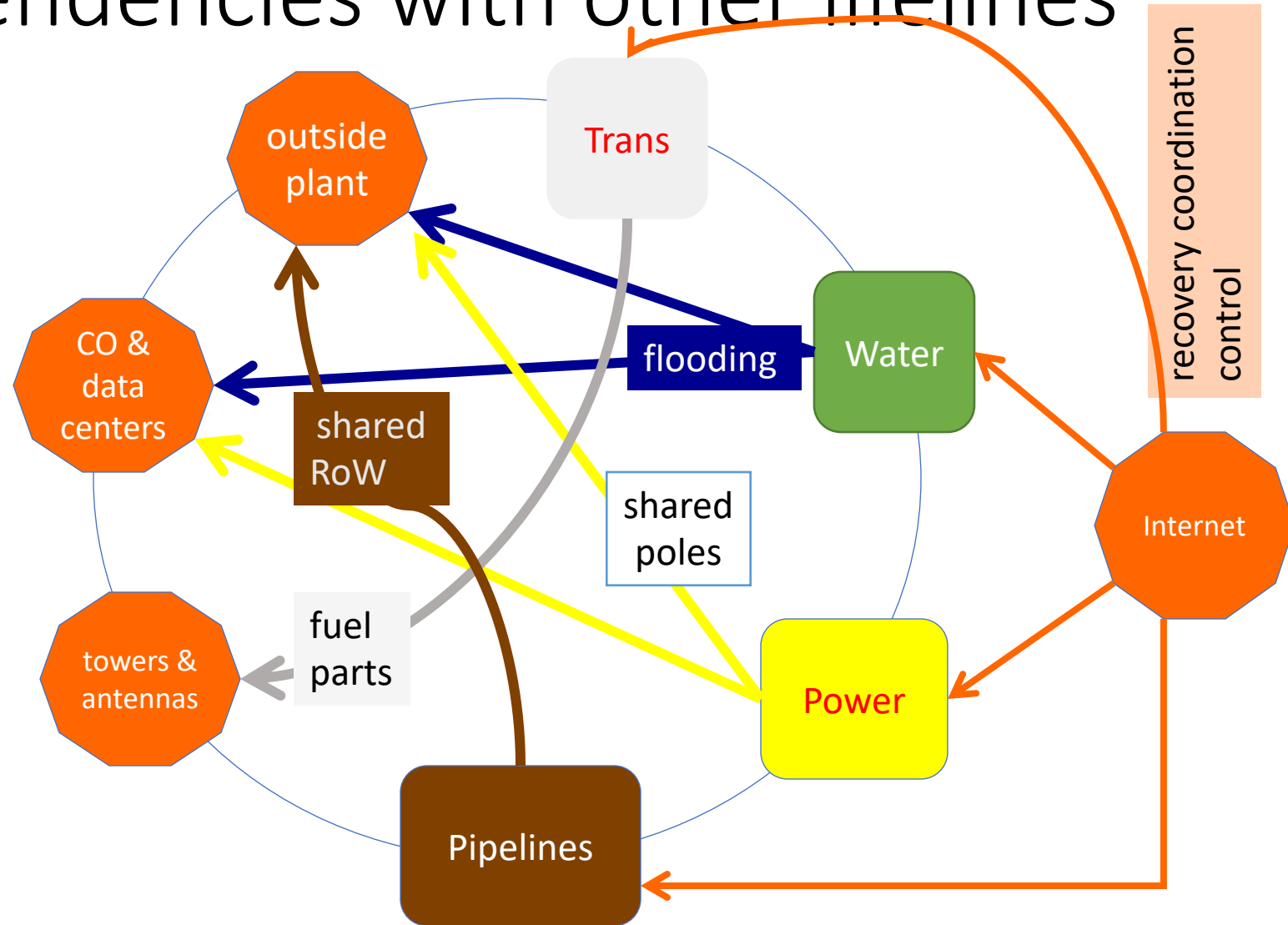
Section 1. Policy. Repeated cyber intrusions into critical infrastructure demonstrate the need for improved cybersecurity. The cyber threat to critical infrastructure continues to grow and represents one of the most serious national security challenges we must confront. The national and economic security 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.

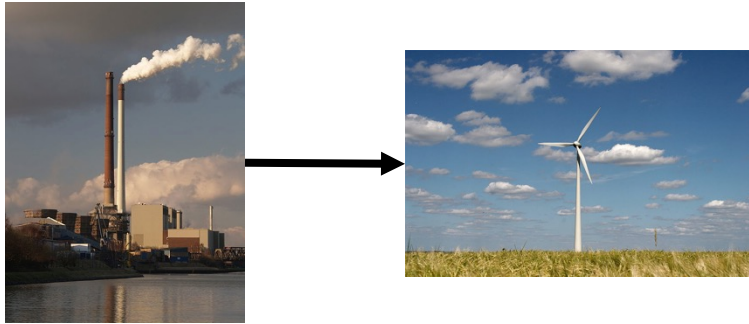


Ted Stevens (R-AK, 2006)

Interdependencies with other lifelines



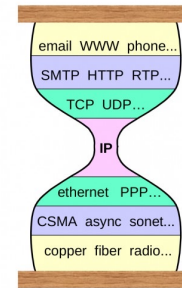
Interfaces: Energy



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

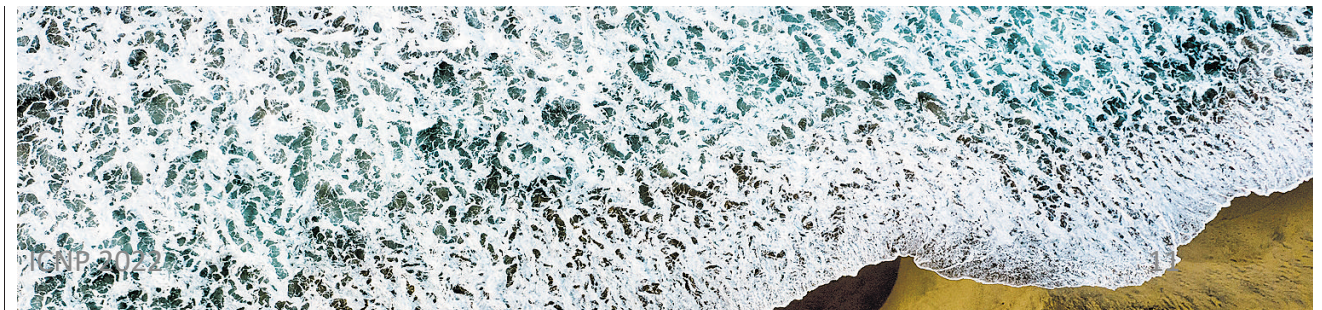
VOL. CLXXI . . . No. 59,202 +

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NEW YORK, TUESDAY, OCTOBER 5, 2021

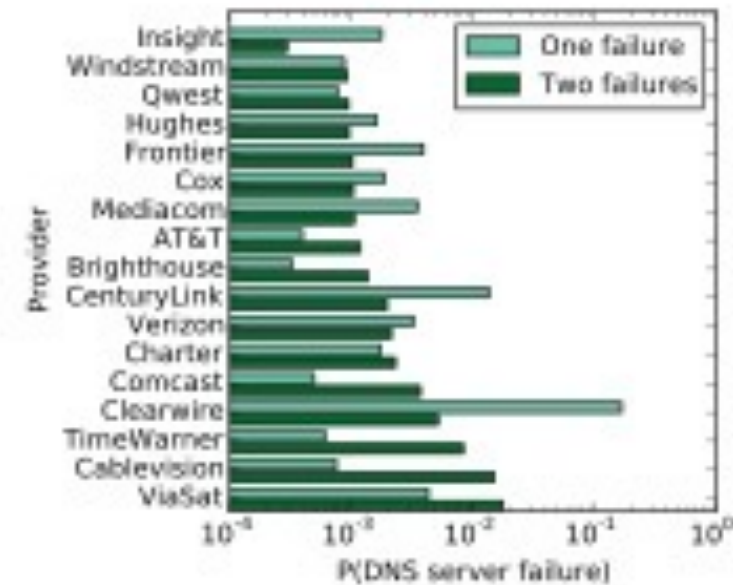
**Facebook Apps
Crash, Leaving
Billions Cut Off**

**Outage Lasting Hours
Has Global Impact**



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

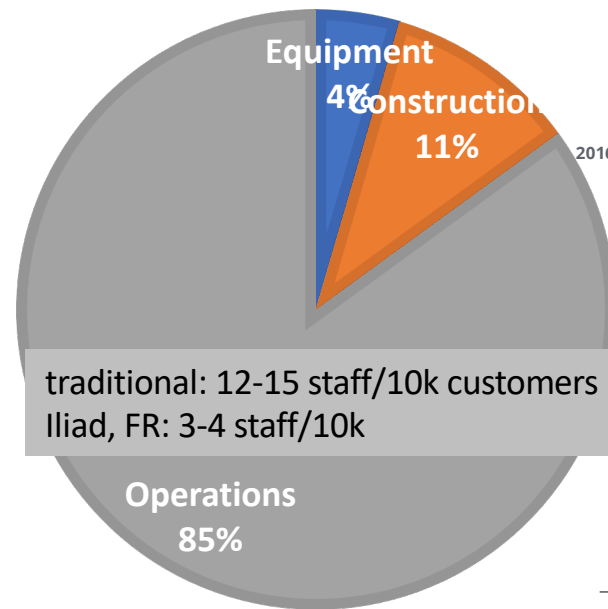
ISP	Average availability			Average annual downtime (hours)		
	1%	5%	10%	1%	5%	10%
<i>Fiber</i>						
Frontier (Fiber)	98.58	99.47	99.77	124	46.8	20.3
Verizon (Fiber)	99.18	99.67	99.80	72	29.2	17.8
<i>Cable</i>						
Bright House	98.21	99.28	99.58	156	62.8	36.7
Cablevision	98.33	99.53	99.70	146	41.4	25.9
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	98.94	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	98.87	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	98.13	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

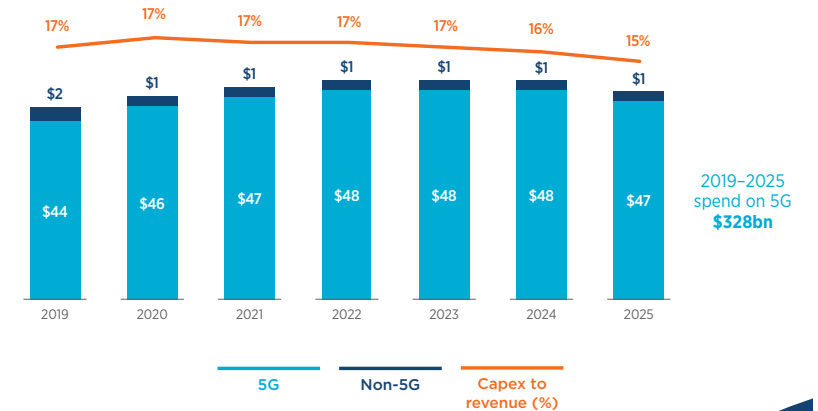
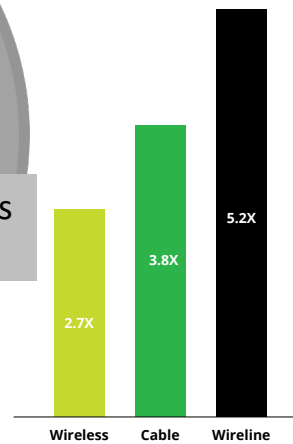
% OF REVENUE

■ Equipment ■ Construction ■ Operations ■



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

2016 Average OPEX to CAPEX ratios⁴⁴

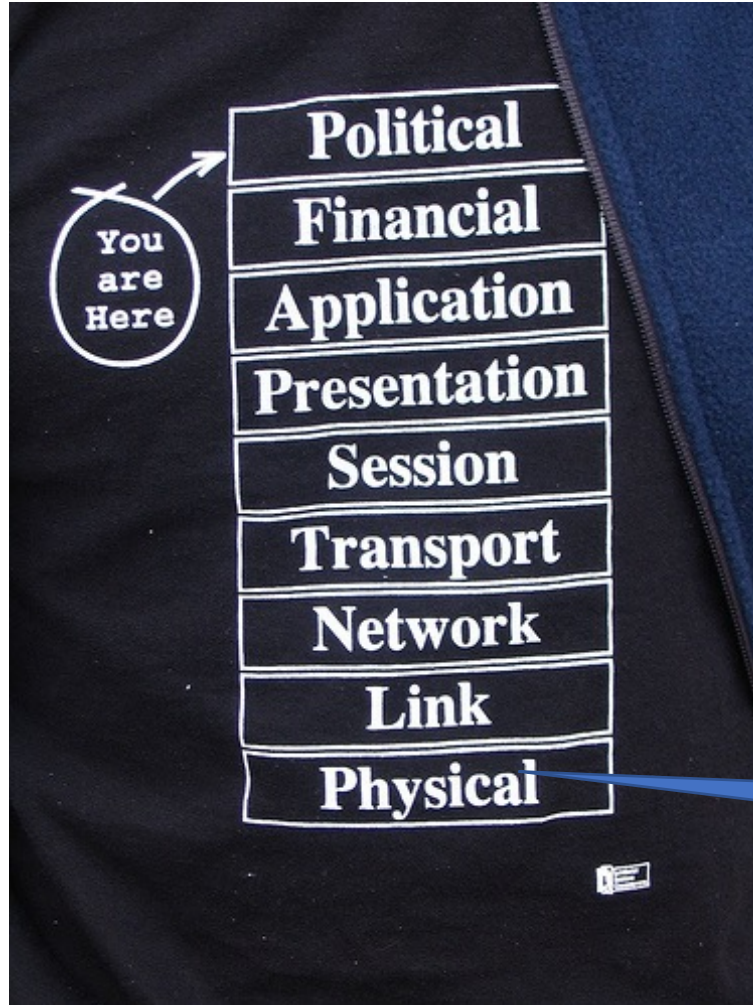


2019-2025 spend on 5G \$328bn

cellular

Performance vs. cost

reliability



This is where the attention is

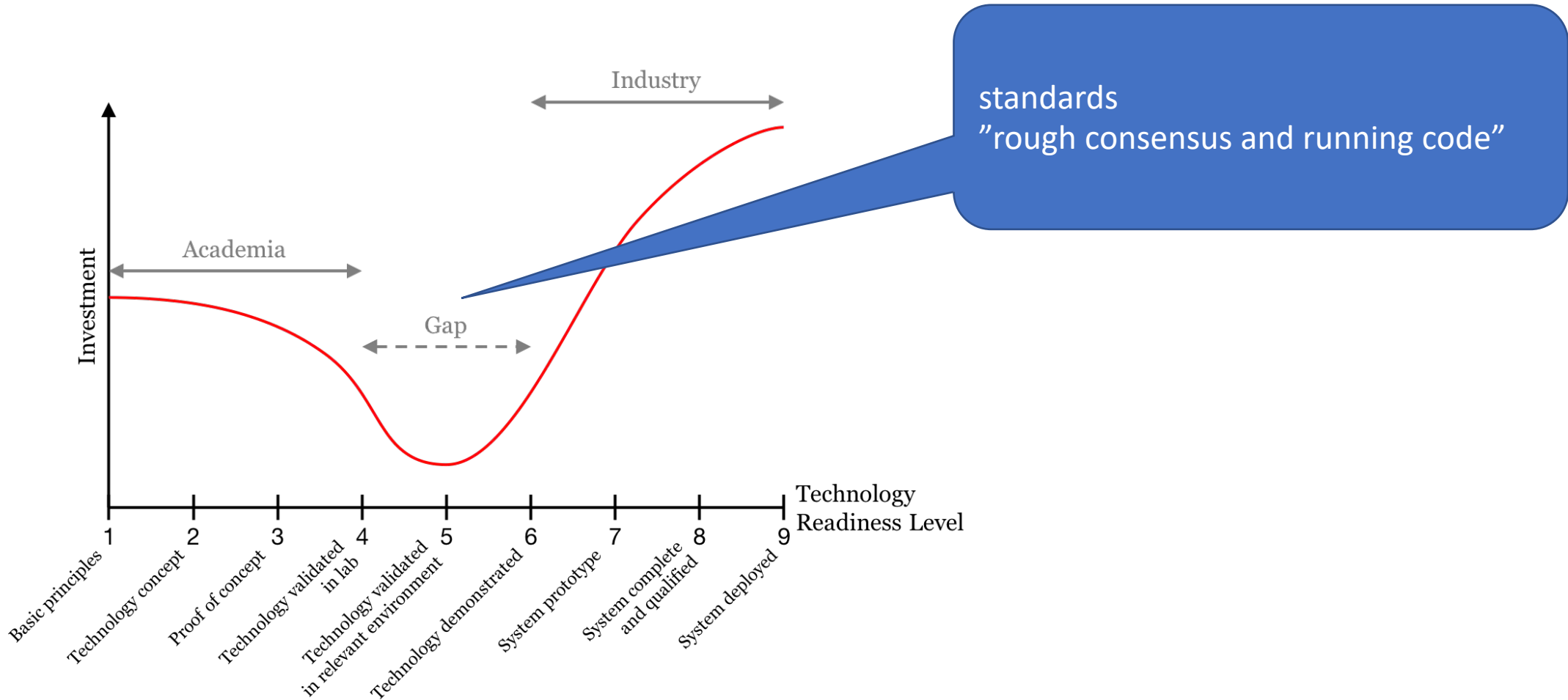
This is where the opex costs are

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

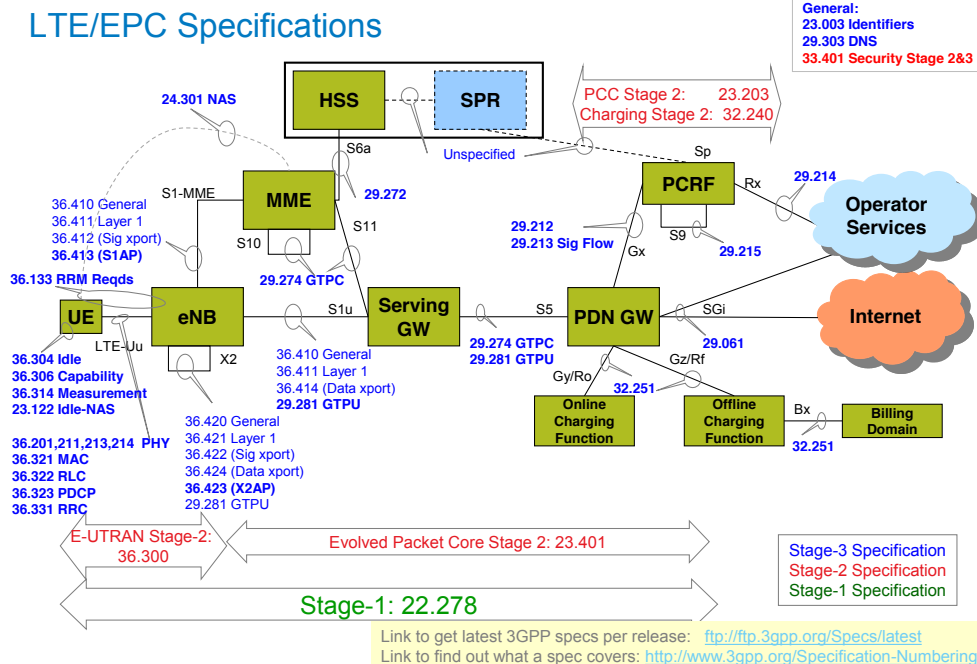


Standards are eco-systems, not one document

What students see:

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

What implementors see:

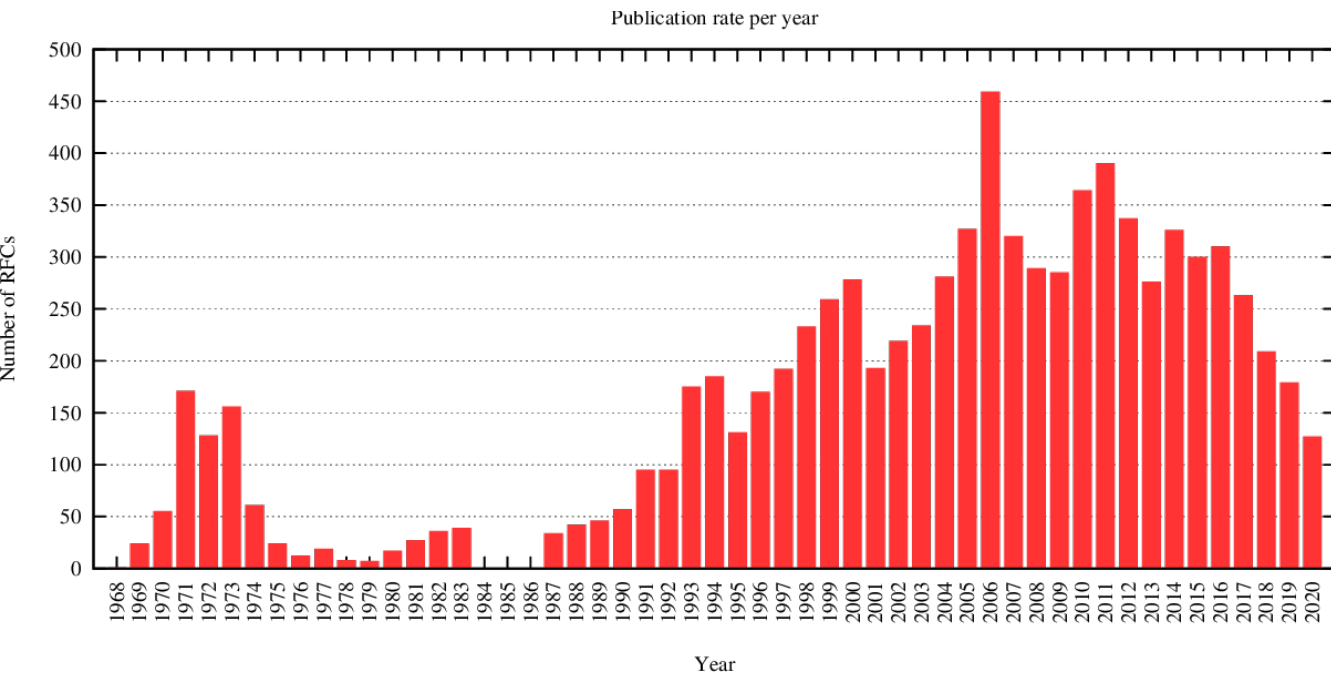


Irfan Ali

Session Initiation Protocol (sip)

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

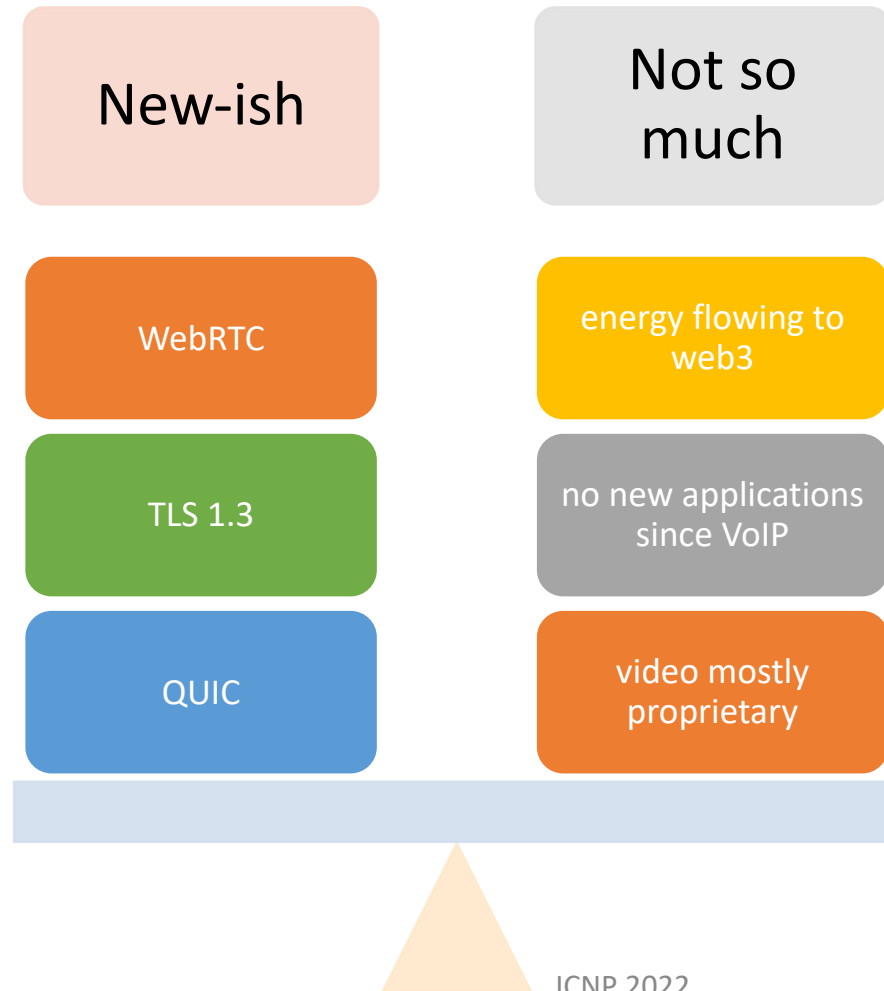
The most important election you never heard of

Tom Wheeler · Friday, August 12, 2022

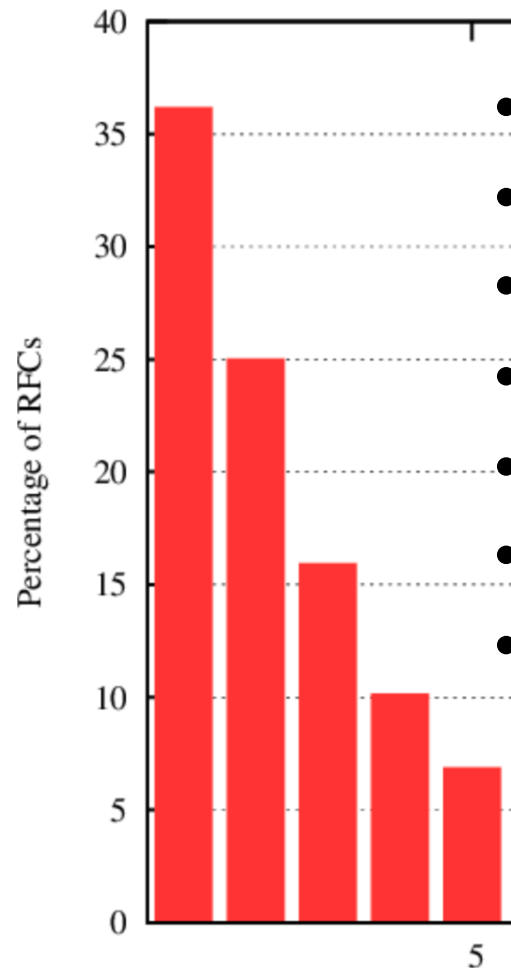
called "internet protocol" or "IP." China has proposed a new standard — called "New IP" — that would give governments more control over internet activities, including the individualized determination of who gets on and what they can do. They want that standard to be driven by the ITU.

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

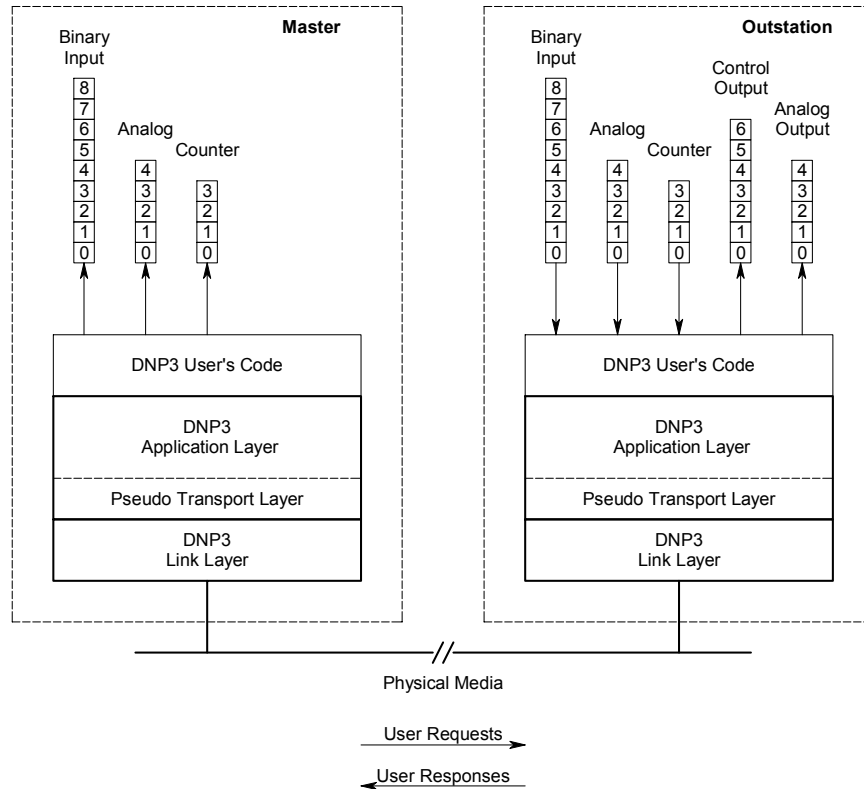


IETF still has a reasonable bar to entry

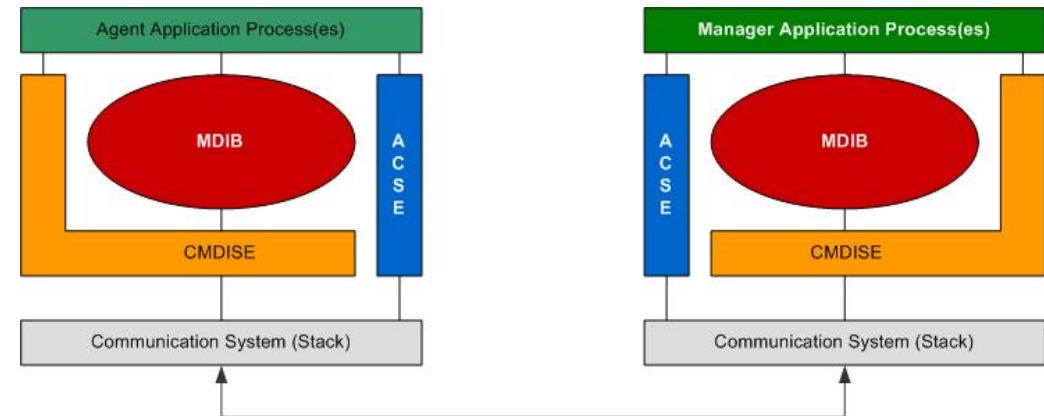


- Most efforts start small – being a graduate student is ok
- Last IETF: 5% of on-site, 8% of online participants academic
- Online participation (meeting & lists) lowers bar
- Get feedback on ideas
- IETF remains good option, but impact uncertain
- 2 approaches: small improvement or new area
- If you're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

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



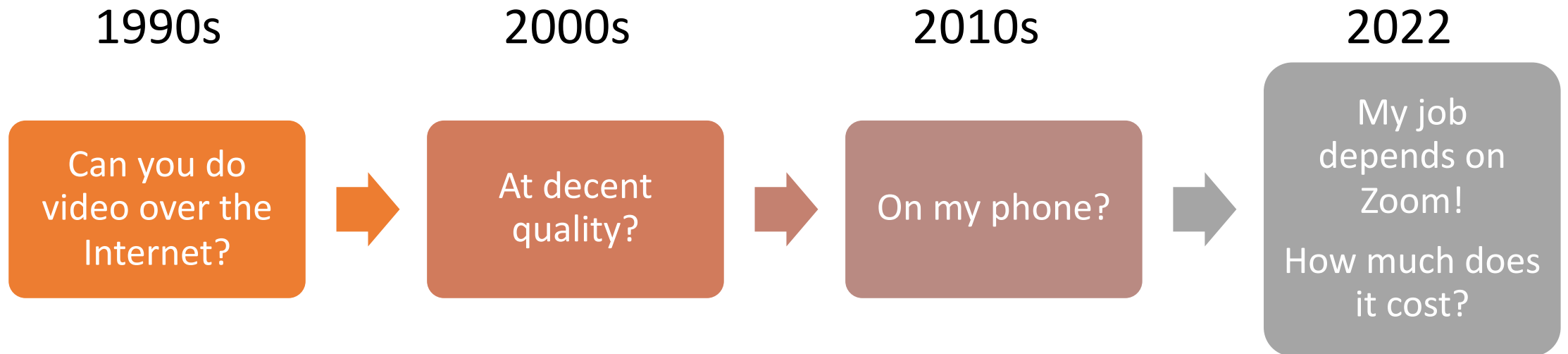
DNP3 (electric utilities)



IEEE 11073 (medical)

We are no longer the young
crowd

Evolution of networking



August 1993

~30 years ago



Display 4.5 in x 1.4 in (114 mm x 36 mm), 160 x 293 pixel
CGA monochrome backlit LCD

Connectivity 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).

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Kurose/Ross, 2000

IETF25 (1992) looks familiar

2 Area and Working Group Reports

2.1	Applications Area	2.5	Operational Requirements Area
2.1.1	Internet Mail Extensions (smtpext)	2.5.1	BGP Deployment and Application (bgpdepl)
2.1.2	Internet Message Extensions (822ext)	2.5.2	Benchmarking Methodology (bmwg)
2.1.3	Network Database (netdata)	2.5.3	Network Joint Management (njm)
2.1.4	Network News Transport Protocol (nntp)	2.5.4	Operational Statistics (opstat)
2.1.5	Network Printing Protocol (npp)	2.5.5	User Connectivity (ucp)
2.1.6	TELNET (telnet)	2.6	Routing Area
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2.2.1	Dynamic Host Configuration (dhc)	2.6.2	IP over Large Public Data Networks (iplpdn)
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2.2.3	IP over AppleTalk (appleip)	2.6.4	ISIS for IP Internets (isis)
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		2.8.3	Domain Name System (dns)
		2.8.4	Service Location Protocol (svrloc)
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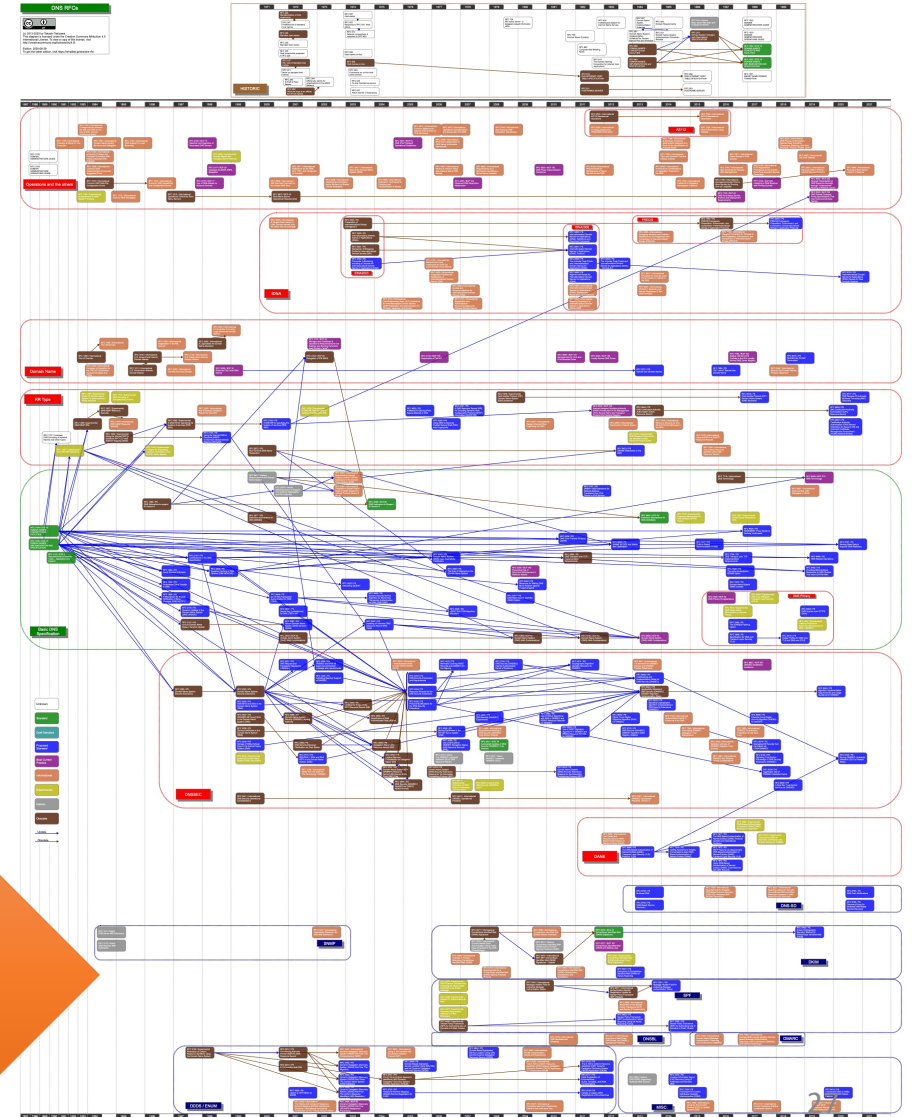
We've met complexity, and it is us



“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)

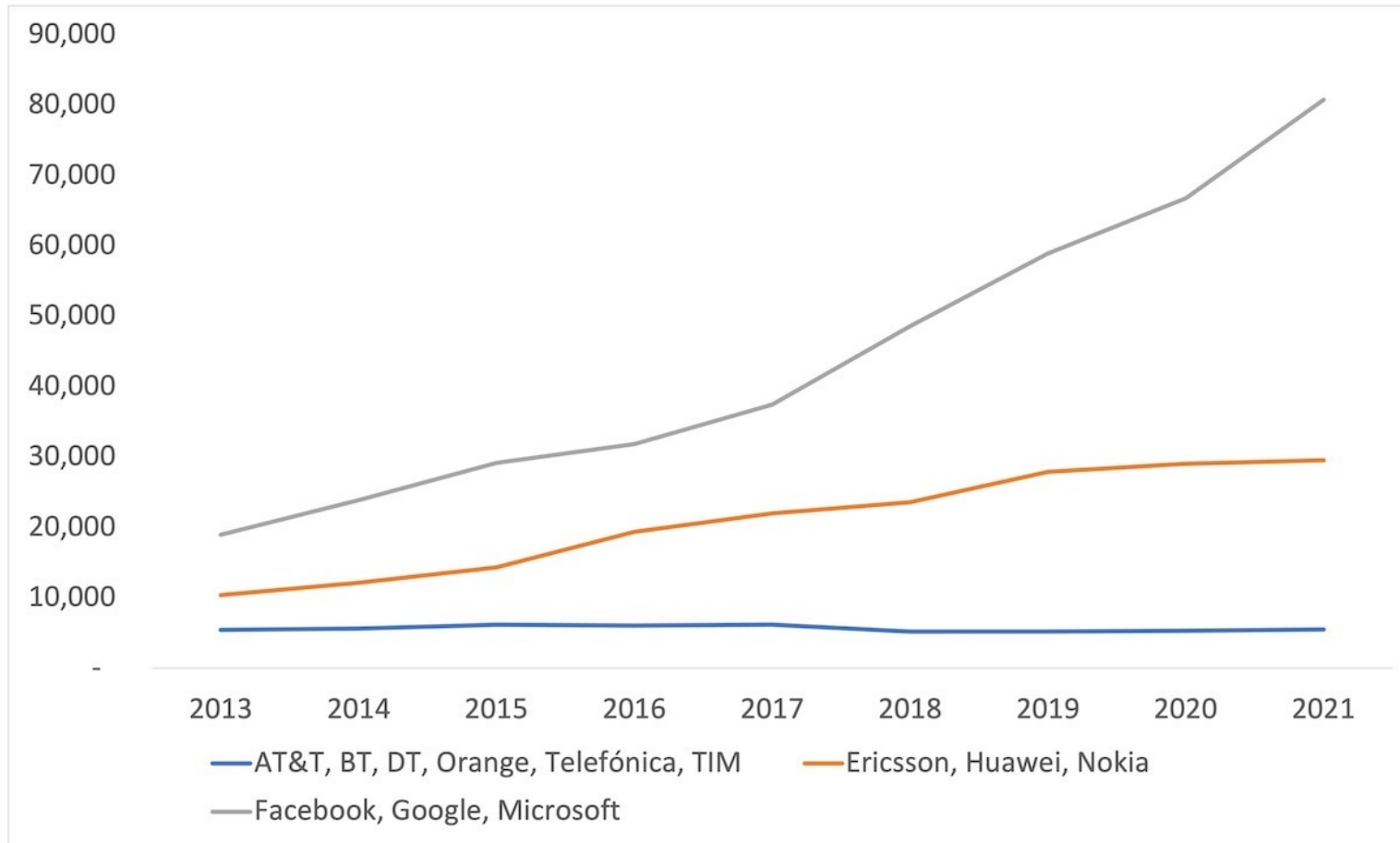
Quagga: 226,048 CLOC

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

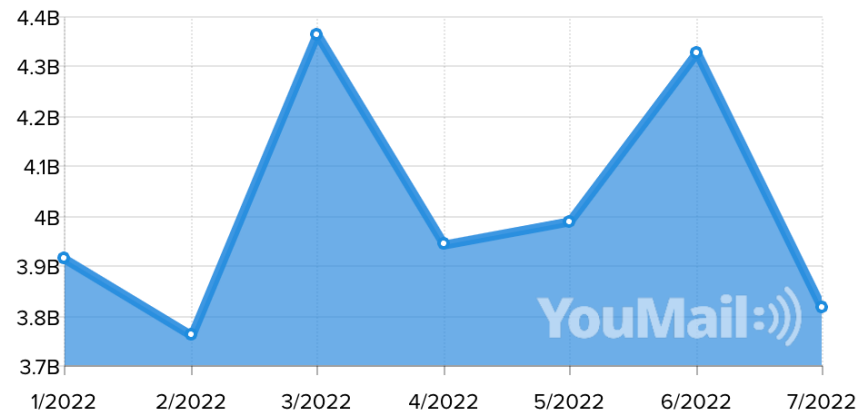
2022 Robocall Impact

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.

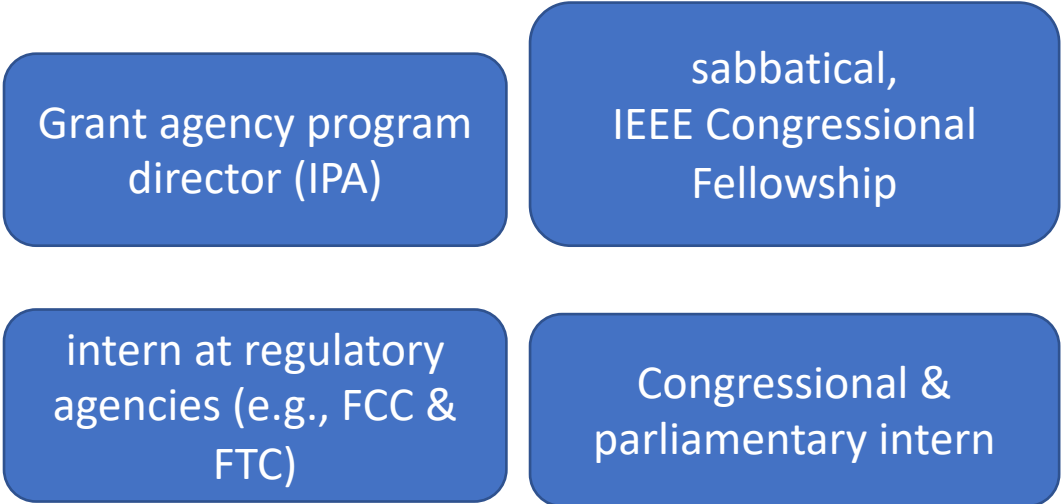
ICNP 2022

"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 University¹) 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.

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eha [Modify Search](#)

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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?

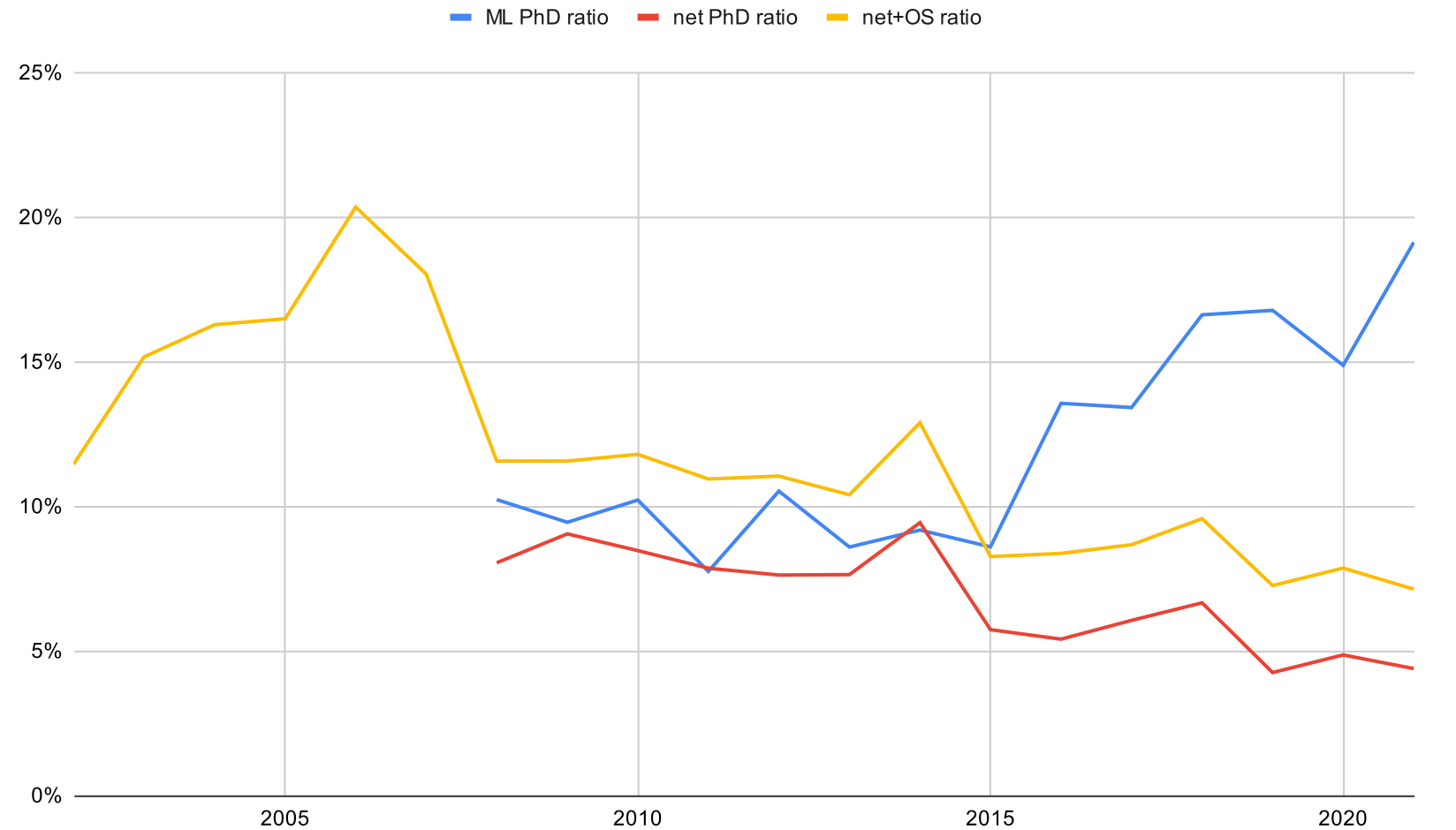
The next generation network(ers)

Networking: now dominated by ML

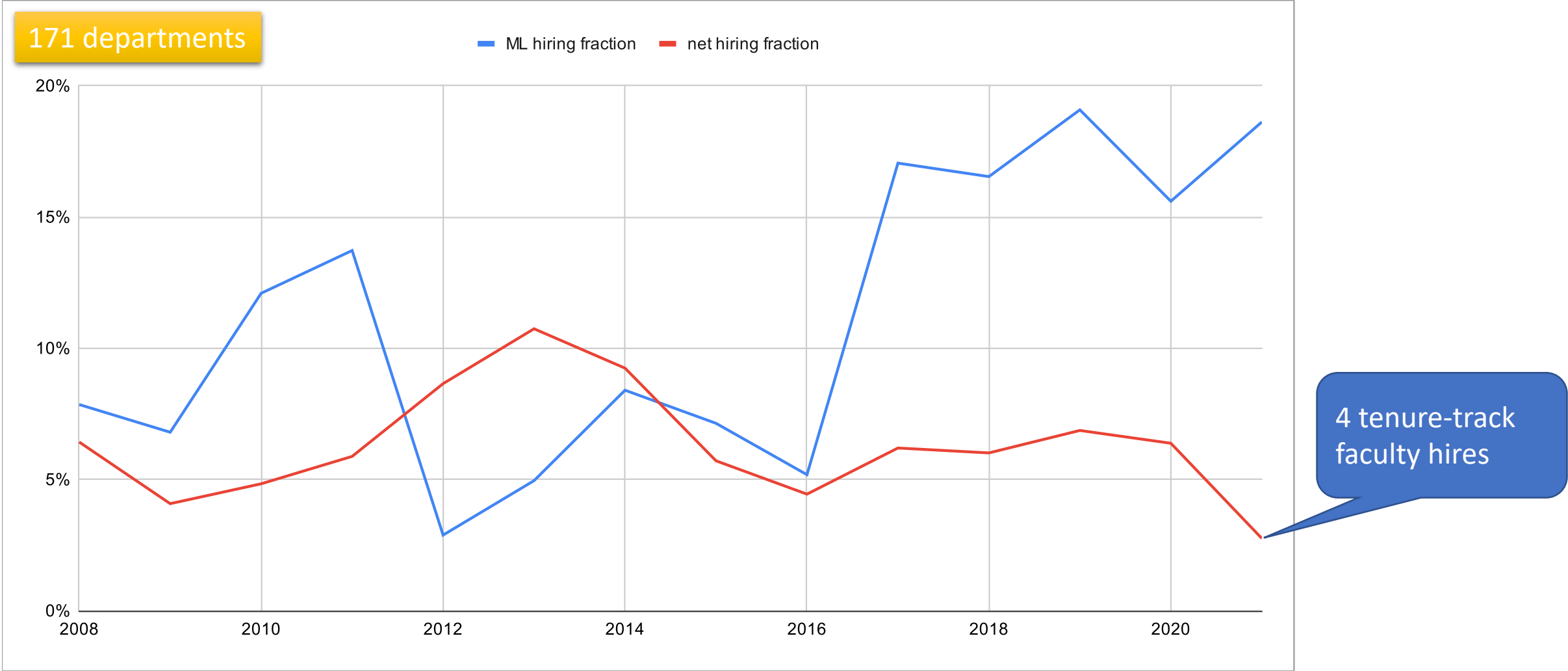
CRA Taulbee Surveys of PhD-granting CS & CE departments in US & Canada

Do we know why?

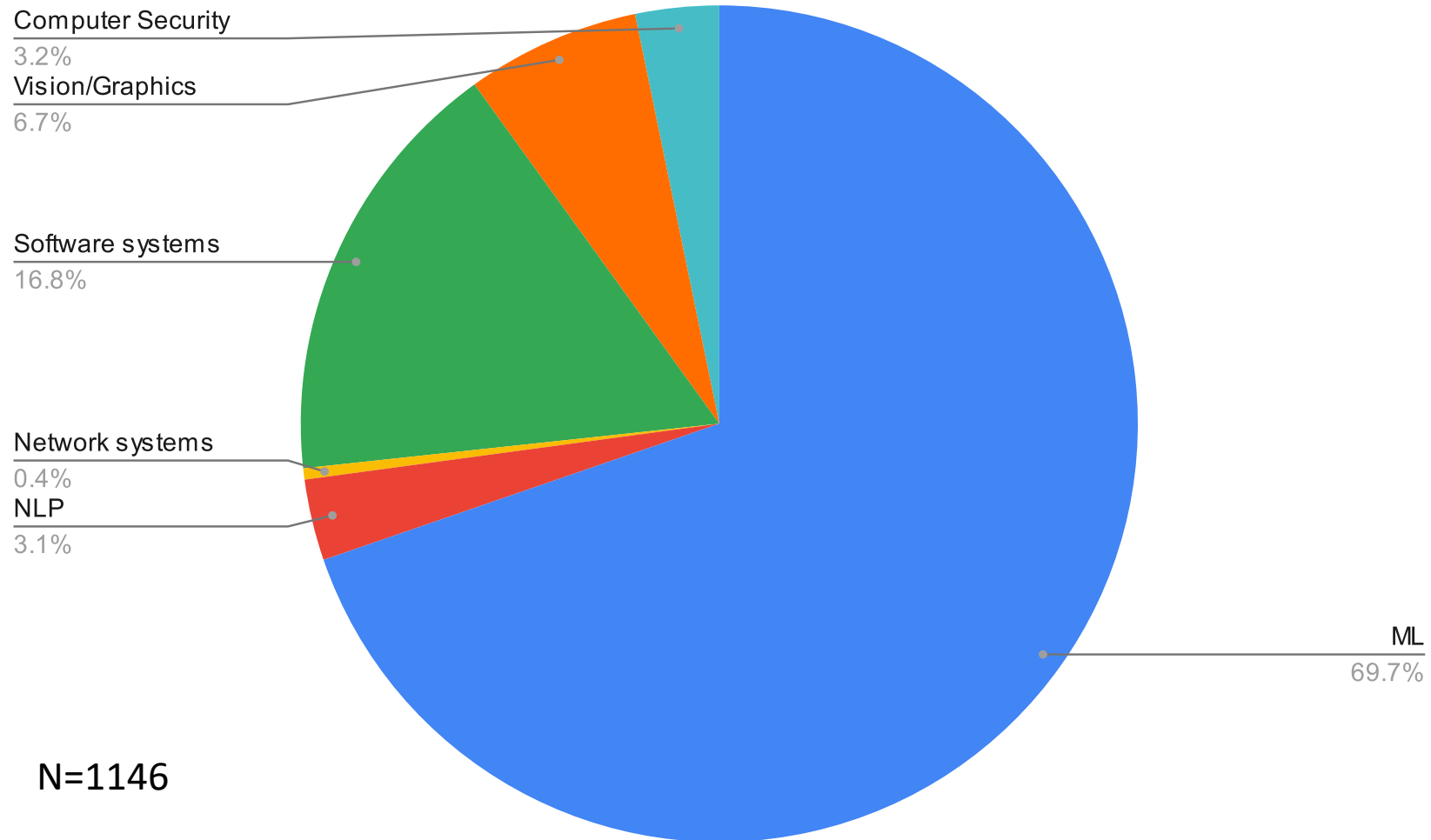
- “petroleum engineering”
- “booring”
- “no jobs”



The faculty pipeline is drying up

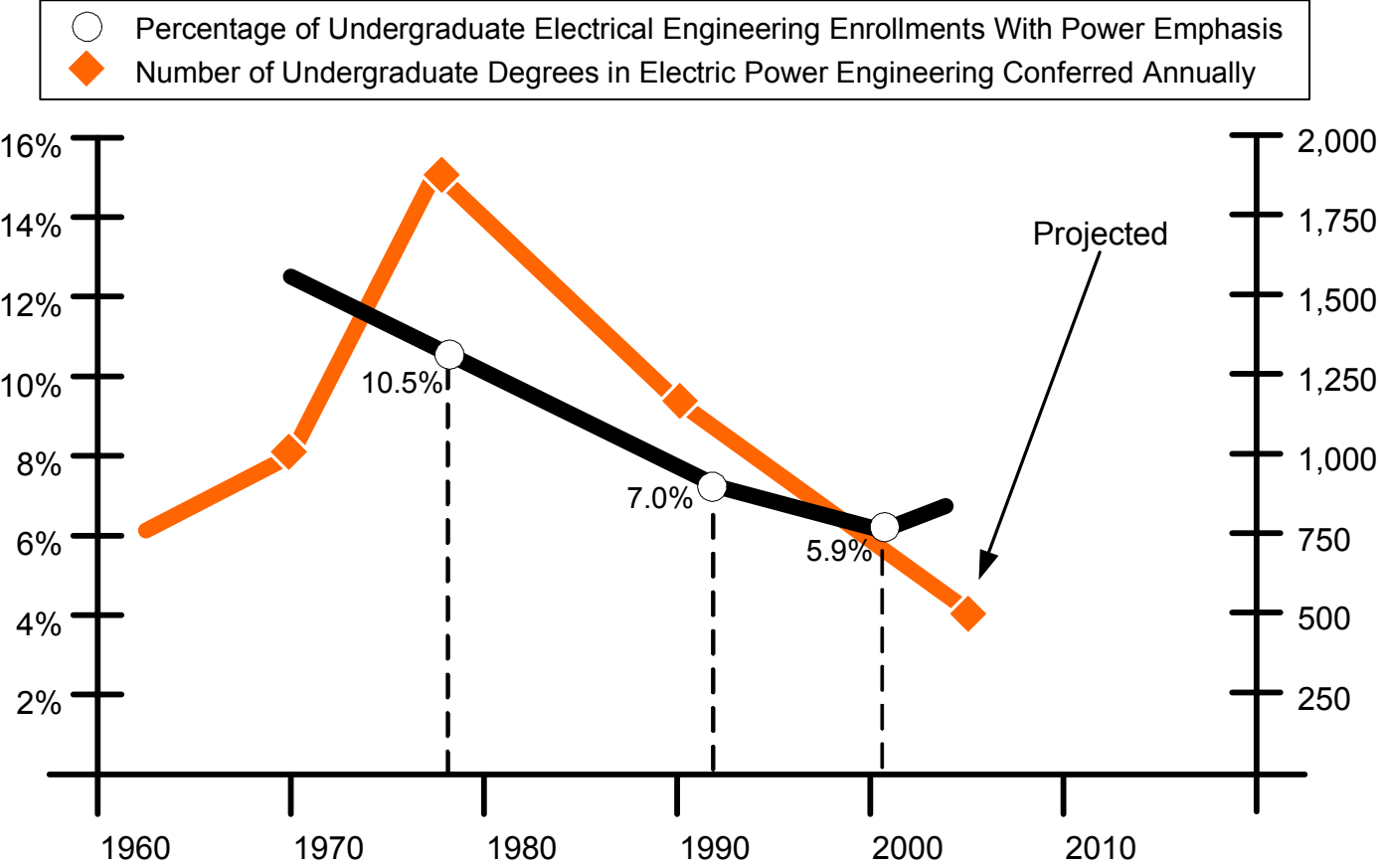


2022 Columbia University CS MS student tracks



N=1146

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



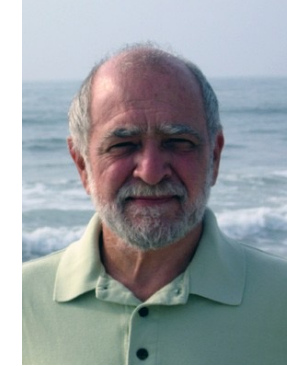
P.A. Ramamoorthy
U Cincinnati



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



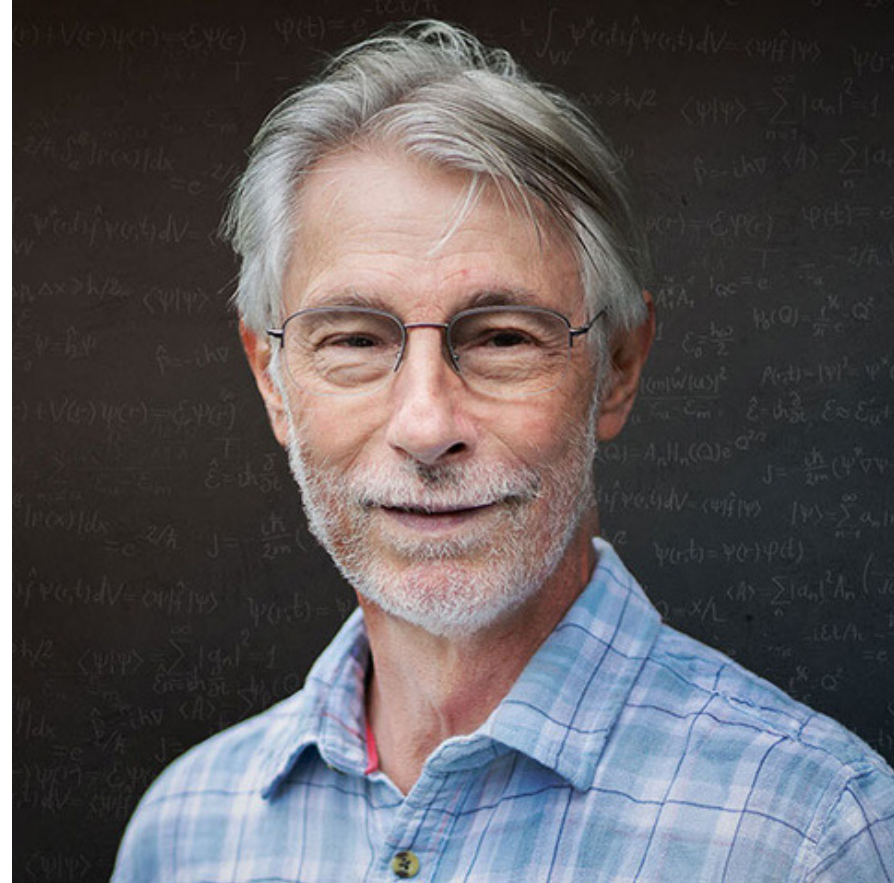
Chris Soghoian
Sen. Wyden

And my academic “parents”



SIGCOMM 2016

8/27/23



SIGCOMM 2008

ICNP 2022

Students, collaborators and co-authors

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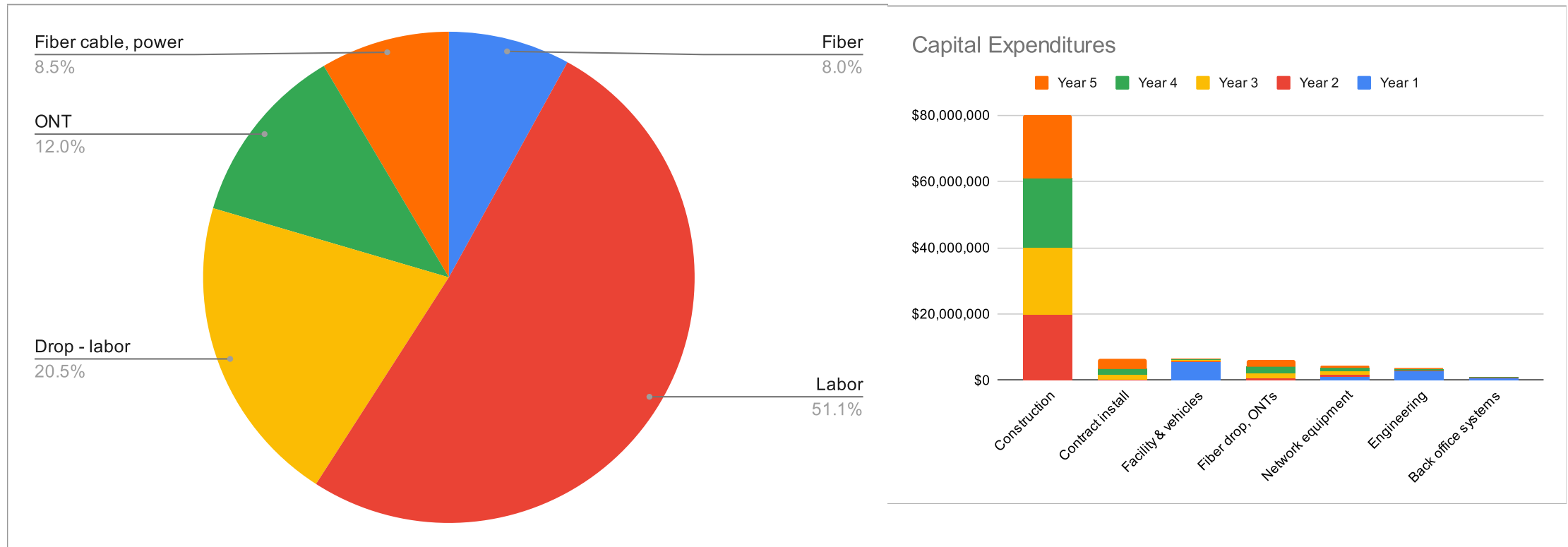
Sangho Shin
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Kundan Singh
Vishal Singh
Henry Sinnreich
Dorgham Sisalem
Wonsang Song
Robert Sparks
Suman Srinivasan
Abhishek Srivastava
Rolf Stadler
Radu State
Peter Steenkiste
James Sterbenz
Tom Taylor
Srisakul Thakolsri
Peter Thermos
Don Towsley
Dirk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

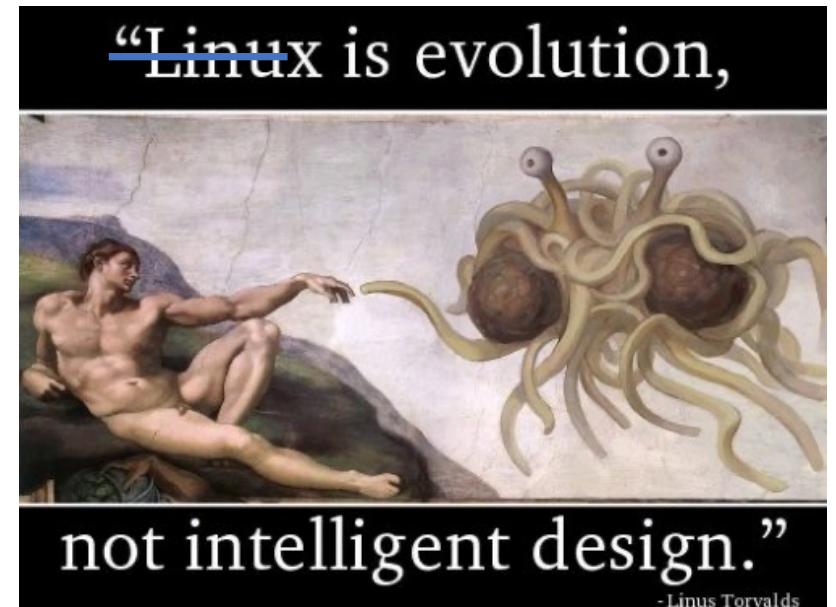
- — *Max Planck, Scientific autobiography, 1950, p. 33, 97*

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

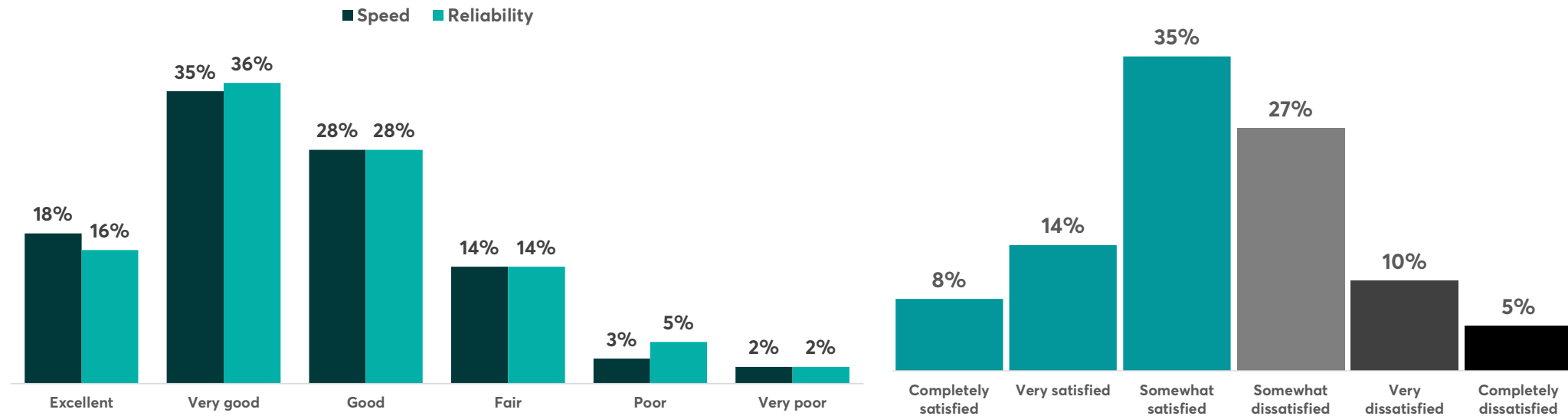
September 1981

ICNP 2022



800 GSM operators

Speed, reliability & price



Consumer Reports, July 2021

My first research job



Academic research vs. government

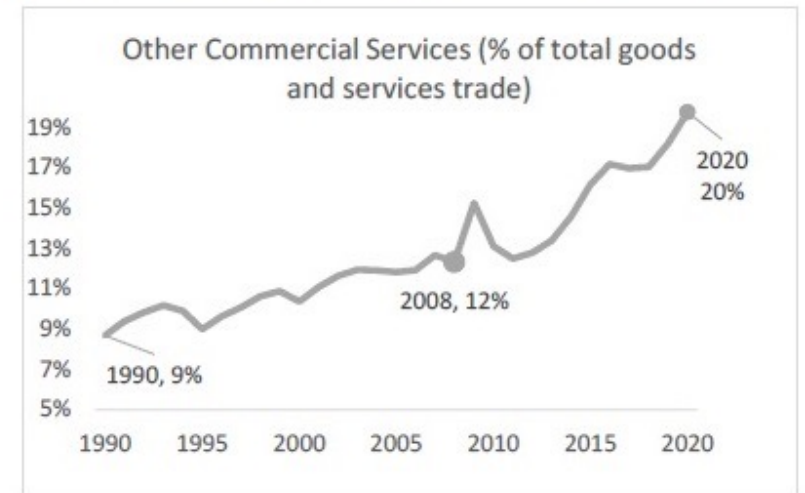
Academic research	Government work
Long deadlines (conference & PhD cycle)	Short deadlines – can be “today”, but can also take a year
Interdisciplinary in proposal; sub-discipline in paper	A lawyer, an economist and an engineer walk into a problem...
Self-motivate + PhD student	Small to large teams
Being 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

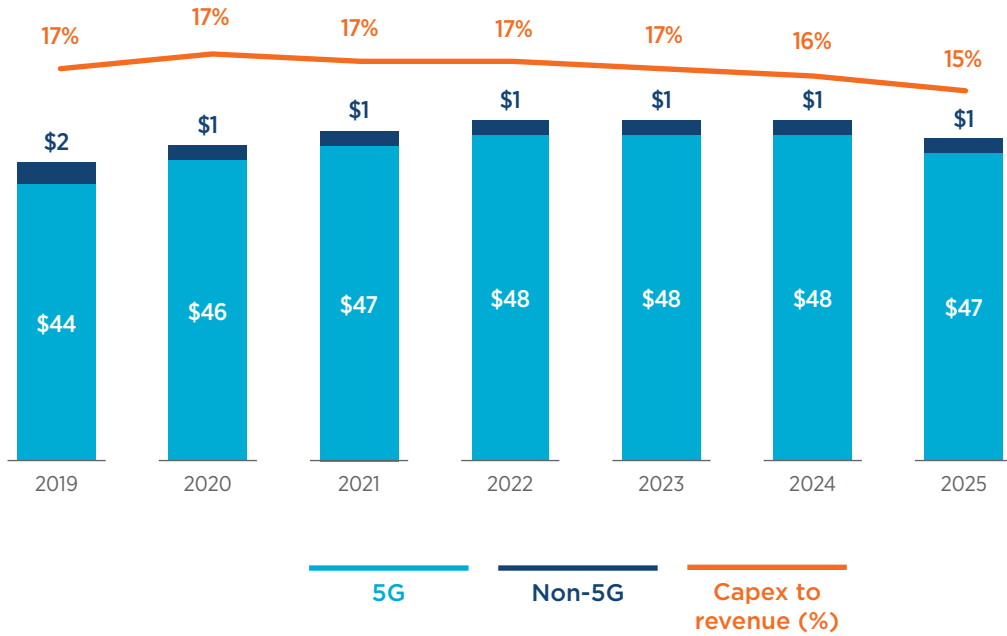
1 st unbundling	lower cost of moving goods	19 th century – 1970s
2 nd unbundling	ICT coordination of manufacturing (off-shoring)	1990s
3 rd unbundling	Internet-based unbundling of services	now

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

