Networking research — A reflection in the middle years

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Review

Networking research — A reflection in the middle years

Henning Schulzrinne ✉

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https://doi.org/10.1016/j.comcom.2018.07.001

Abstract

Networking is no longer a new area of computer science and engineering – it has matured as a discipline and the major infrastructure it supports, the Internet, is long past being primarily a research artifact. I believe that we should consider ourselves as the civil engineers of the Internet, primarily helping to understand and

We’re all getting older

It’s been a while…

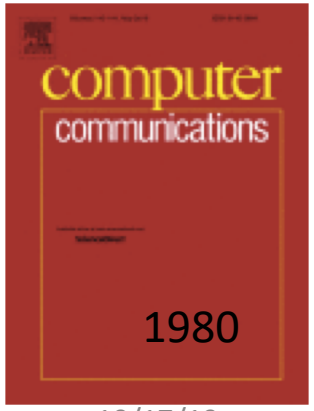
RFC: 793

TRANSMISSION CONTROL PROTOCOL

DARPA INTERNET PROGRAM

PROTOCOL SPECIFICATION

September 1981



INFOCOM 82

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Monday March 29th, 1982

1 COMPUTER NETWORKS

Data communications is the glue holding together dispersed terminals, computers, and people. While at one time one would engineer a “data comunications system” for a specific purpose, today you have the choice of connecting to or purchasing a “computer network.” If you are concerned with design, operations or cost alternatives for non-trivial data/computer communications, this tutorial is for you.

It is common practice to employ computer networks for interconnecting various components and sites. International standards activities have heightened the prospect of global, interconnected networks, while non-standard architectures persist and countries threaten to control the data passing through their borders. Full exploitation of network capabilities requires a thorough understanding of both

Fifty Years of RFCs

April 7, 2019 marks the fiftieth anniversary for the RFC Series, which began in April 1969 with the publication of “Host Software” by Steve Crocker.

While the Series itself predates the Internet Engineering Task Force (IETF) by eighteen years, today the IETF is the single largest source of RFCs. It’s an interesting question – did the existence of a growing community that published technical documents like RFCs result in forming the IETF? Further, is the IETF the reason RFCs are still published today? The Series includes documents originating in other ways, including from the Internet Research Task Force (IRTF), the Internet Architecture Board (IAB), and contributions via the Independent Submissions stream; they are a small, and important, percentage of the whole.

25 years ago

August 1993

Display	4.5 in × 1.4 in (114 mm × 36 mm), 160 × 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)

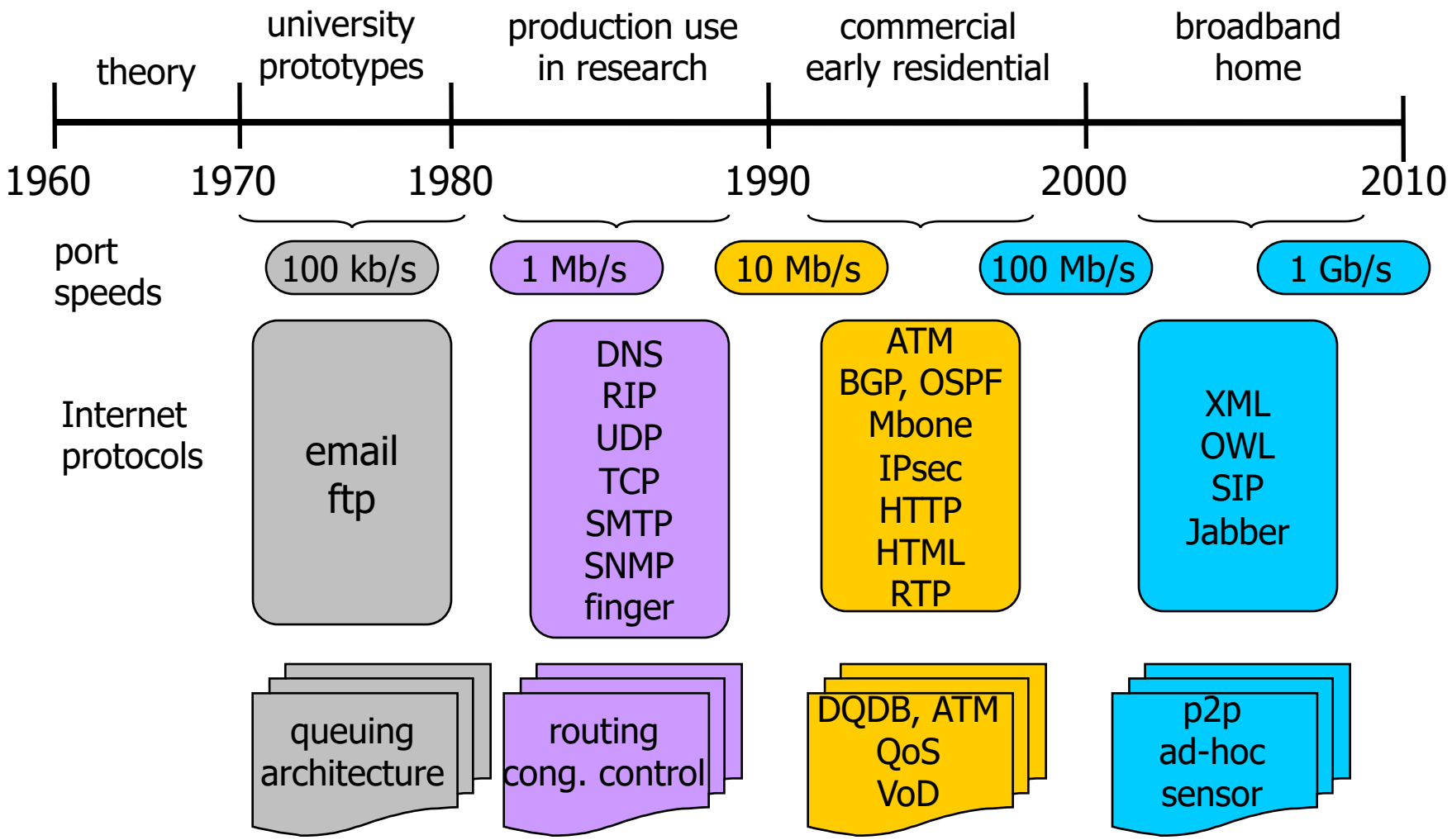
Mosaic 1.0: November 1993

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

/iew 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 Hardenbergplatz 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)

Internet and networks timeline



Fully new (scale) applications are extremely rare

Application	First demonstrated (on Internet)
Video	1992: mbone (multicast audio & video)
Augmented reality	1968: Ivan Sutherland invents the head-mounted display and positions it as a window into a virtual world
Virtual reality	1979: Eric Howlett developed the Large Expanse, Extra Perspective (LEEP) optical system
IoT	1985: term ”Internet of Things” used
Connected cars	2001: OnStar remote diagnostics
Games	1984: “Islands of Kismai” (first commercial online game)

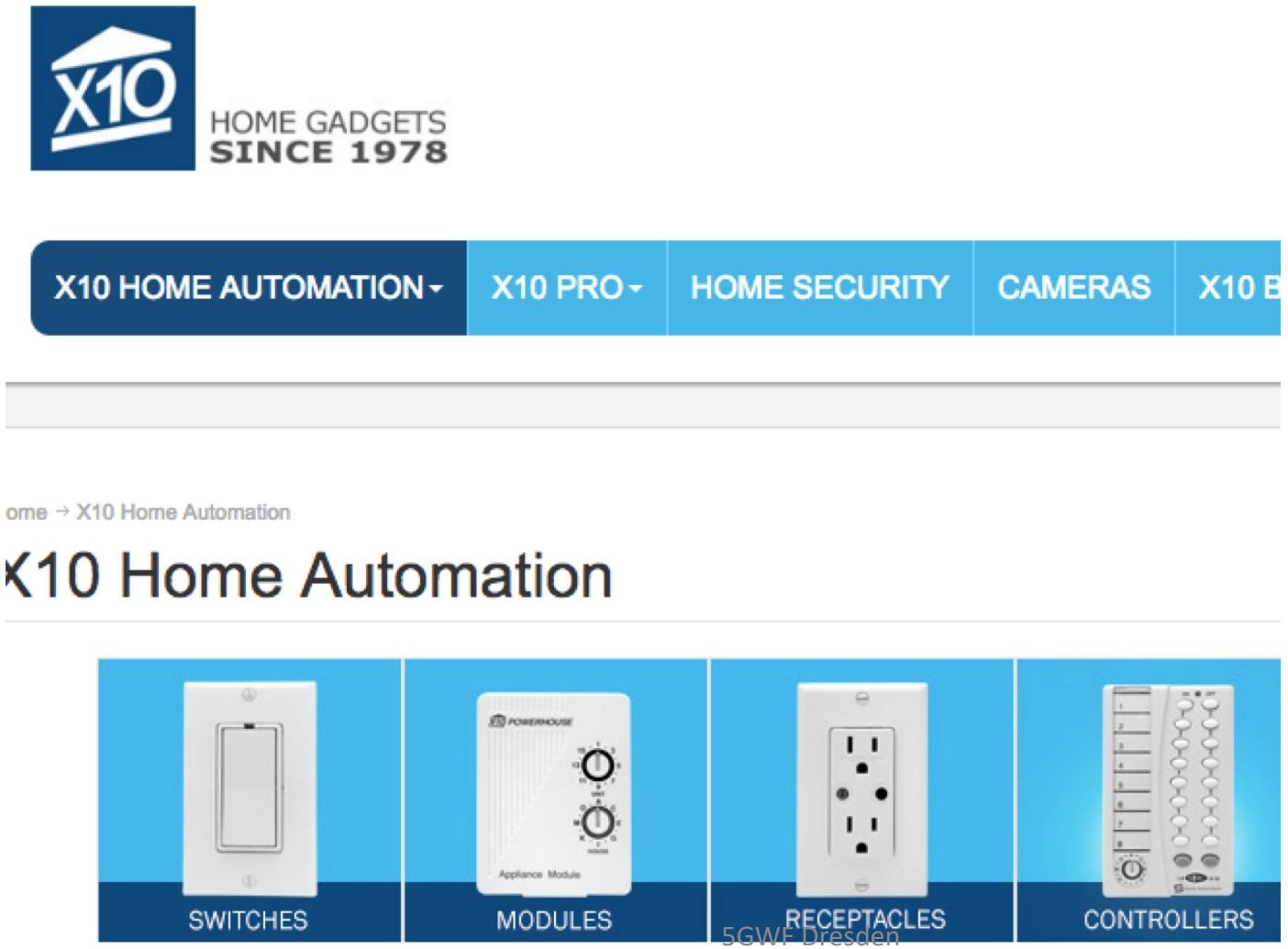
better

faster

cheaper

mobile
fewer wires (last hop)

IoT is not exactly new (1978)



We’re civil engineers repaving roads

The great infrastructures

- Technical structures that support a society → "civil infrastructure"
  - Large
  - Constructed over generations
  - Not often replaced as a whole system
  - Continual refurbishment of components
  - Interdependent components with well-defined interfaces
  - High initial cost

water

energy

transportation

communication

We’re done


Telegraph
• text only
Telephone
• voice + text
Internet
• anything digital

Once developed, basic functions don’t change

1908 (1925)

1958

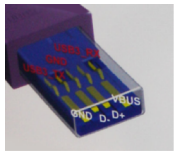
Interfaces define industries (and stay the same)

110/220V

NEMA 1-15R

~1915 (2 prong)

- Lots of other (niche) interfaces
- Replaced in a few applications



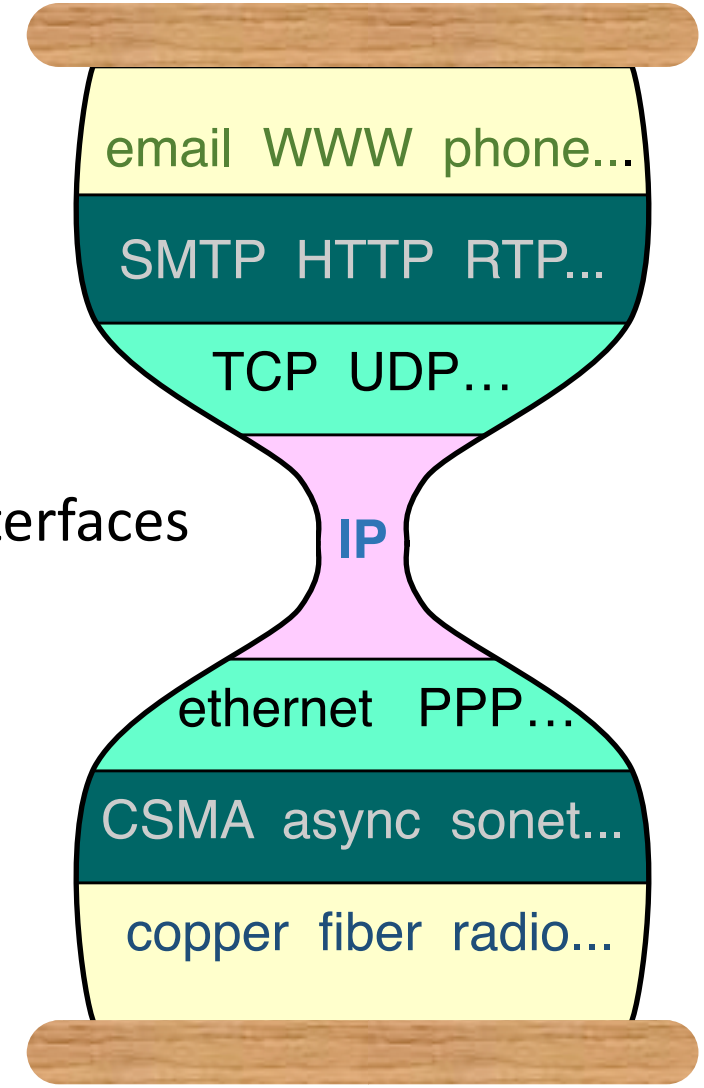
1901

http://www.centennialbulb.org/cam.htm

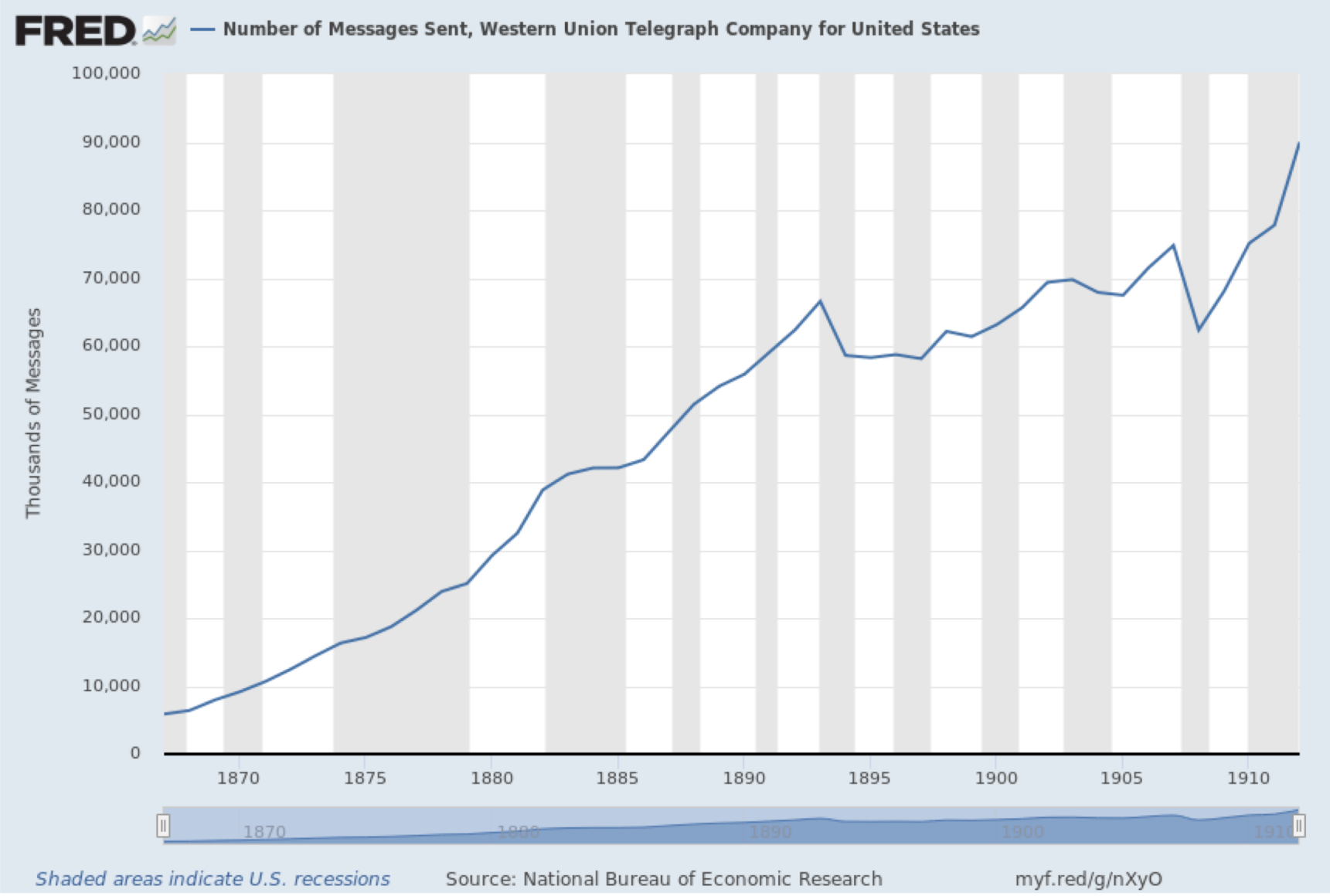
The Internet Protocol Hourglass

S. Deering, 2001

small number of long-term stable interfaces



The Victorian Internet



It always takes longer than you think

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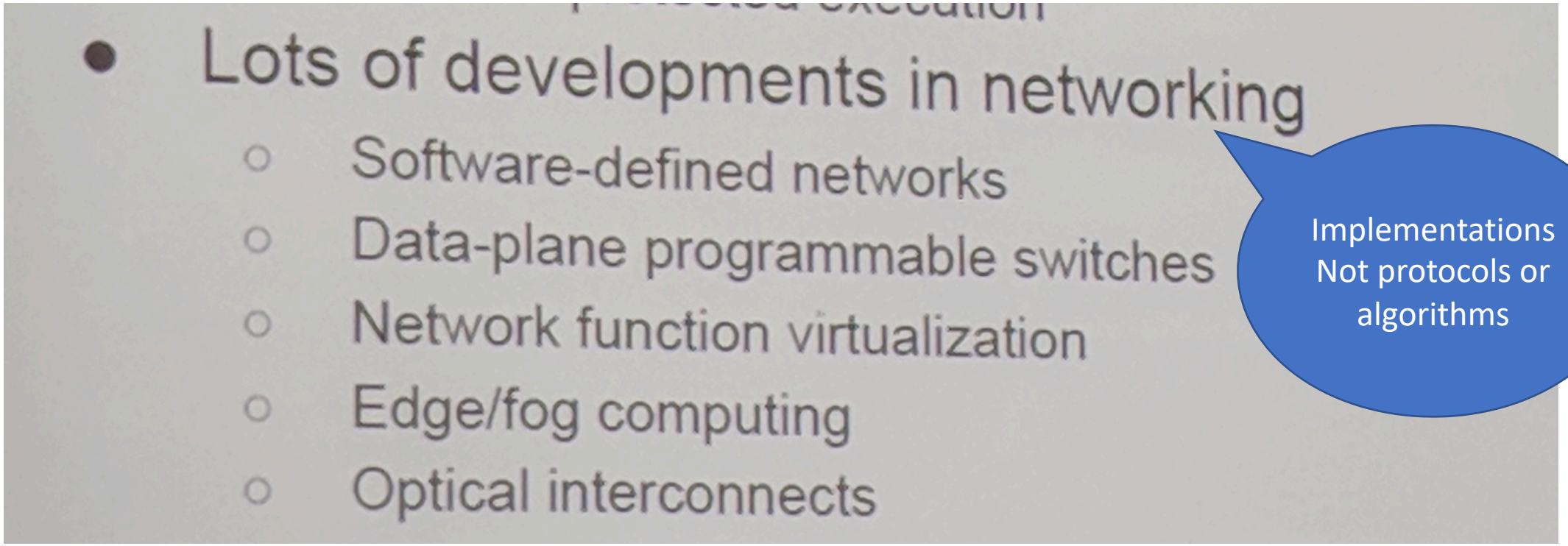
Kurose/Ross, 2000

IETF25 (1992) looks familiar

Why so little change in the Internet?

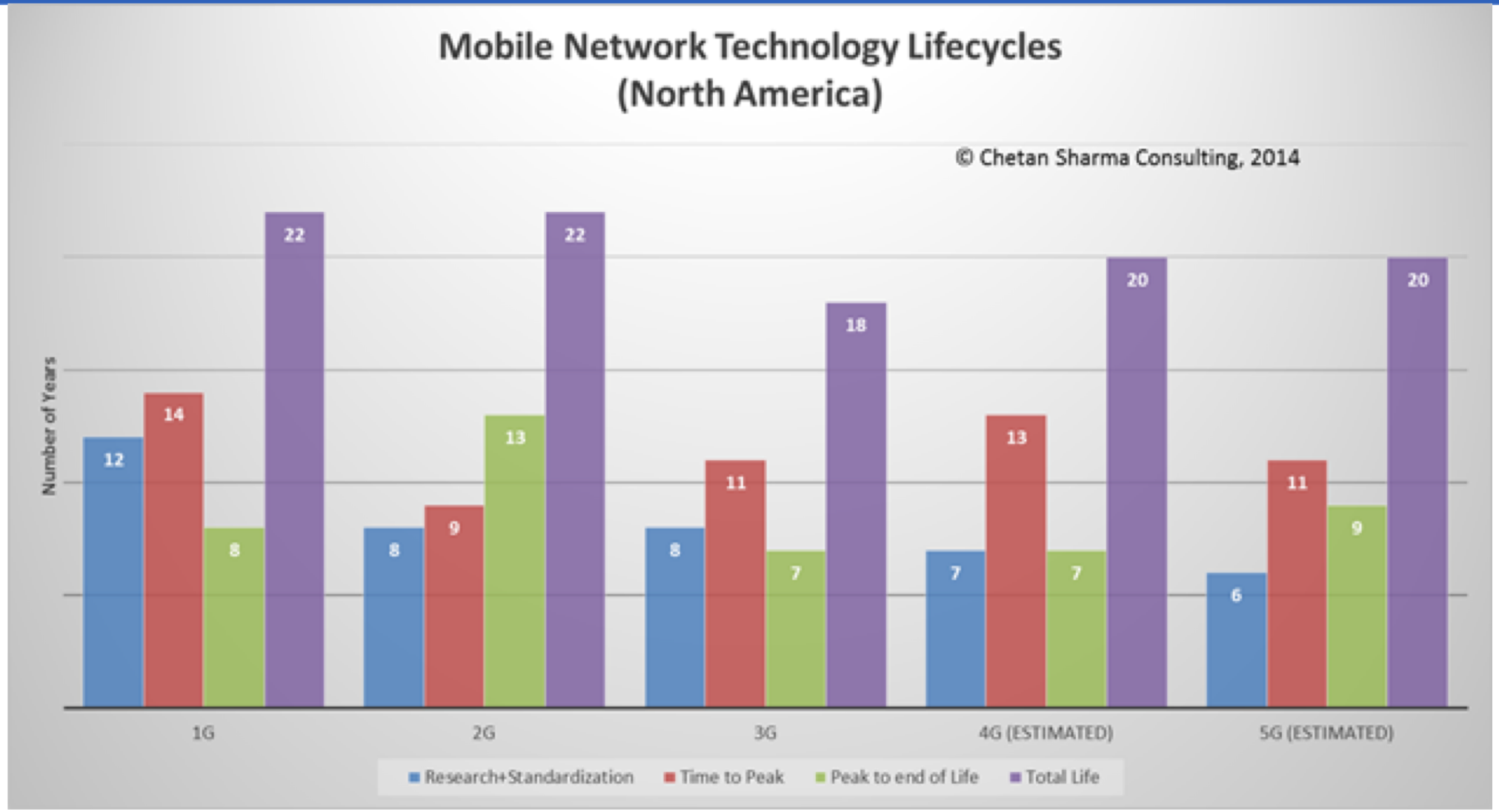
	Browser	Data center	Access networks	Internet
Major changes in last decade	WebRTC, HTML5, WebSocket, CSS3, …	SDN, heterogeneous computing, rack-scale, accelerators	5G, DOCSIS 3.x	QUIC
Major players	3	4 (or 7)	Major wireless Comcast	Hundreds to thousands
Backward compatible	Easy	Local	Separate frequencies	Minimum feature set
Incentive	Competition	Revenue	Spectral efficiency	Limited (OpEx?)

Random Dagstuhl slide



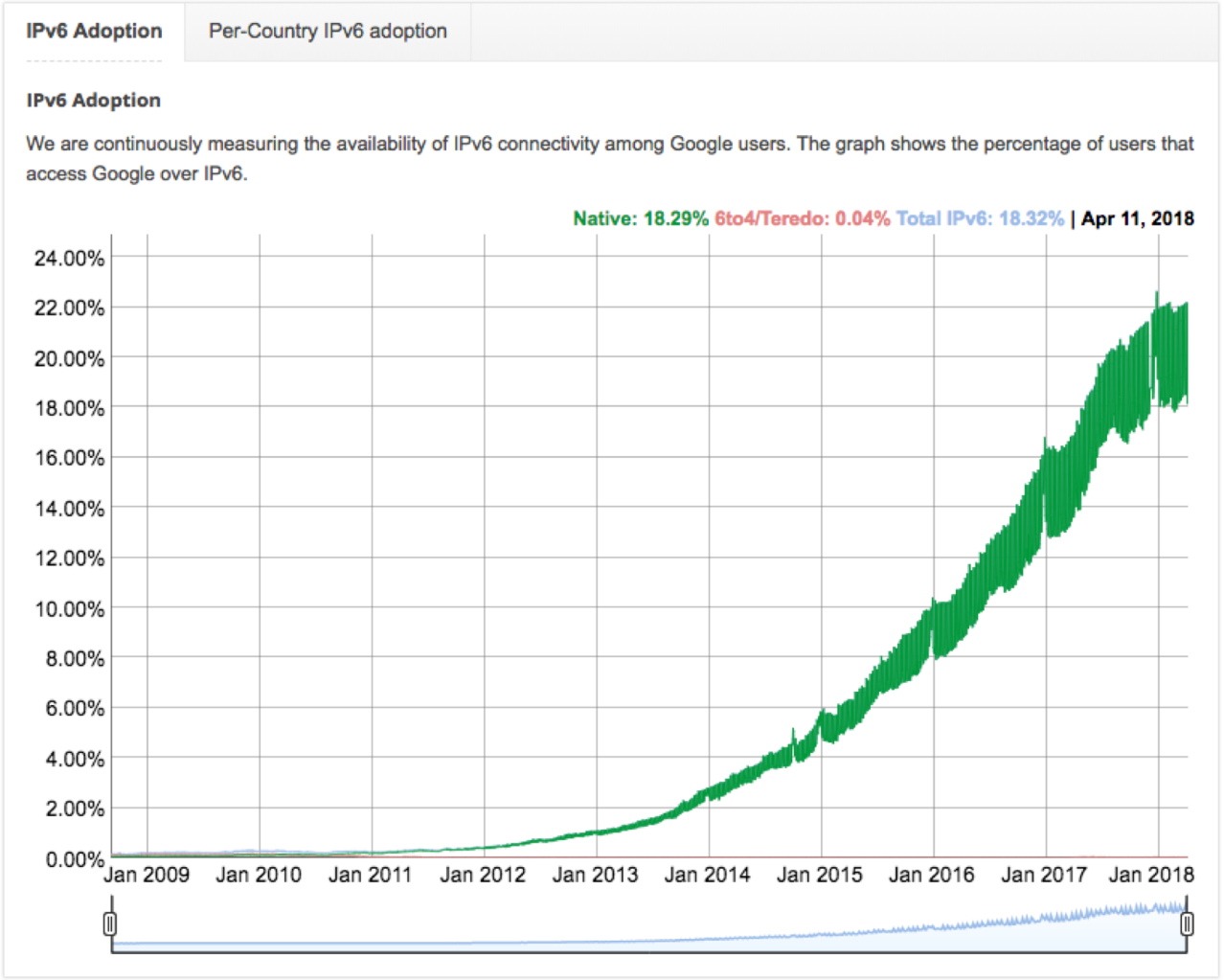
With exception of QUIC and maybe YANG, no major new protocols in last 10 years.

Design for 20 years



“The future has arrived — it’s just not evenly distributed yet.” (Gibson, 1992)

IPng WG: July 1994
RFC 2460: December 1998



Telecom infrastructure

The book value of the top 30 telcos' fixed assets is more than $2.4 trillion. If sold at market value, theoretically these assets could be enough to **wipe debt off their balance sheets.**

Networks never die, they just drop nodes

The fax of life

It's 2017. Why does American medicine still run on fax machines?

Updated by Sarah Kliff | sarah@vox.com | Oct 30, 2017, 8:00am EDT

The Communications Security, Reliability and Interoperability Council V
Final Report

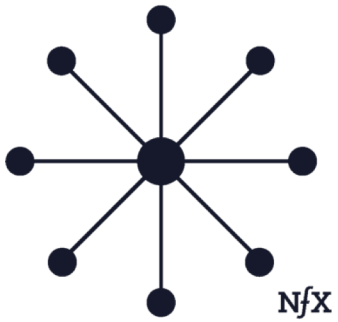
Working Group 10
March 2017

years of rapid growth in mobile communications, the scale of SS7 approaches Internet proportions. Today, networks based on SS7 protocols manage the circuit-switched links among hundreds of carriers for wireline and wireless services and operators serving the majority of the 7.46 billion mobile subscribers worldwide as of June 2016.[3]

➔ We'll still have phone numbers and IPv4 addresses in 2043…

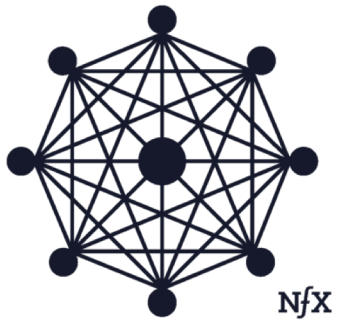
The inverse network effect

Sarnoff's Law



$V=n$

Metcalfe's Law



$V=n^2$

Reed's Law

$V=2^n$

The difficulty of changing a network is exponential to its size.

Simple core protocols have acquired technical debts

RFC	Type	Status	Title	Bgnd	Prot	Names	Ops	RR	Proxy	Stub	Auth	Res	Xfr	DDNS	DNSSEC
882		Obsolete	Domain Names – Concepts and Facilities	x		x	x				x				
883		Obsolete	Domain Names – Implementation and Specification		x		x	x			x	x			
920			Domain Requirements				x								
973		Obsolete	Domain System Changes and Observations			x		x			x	x			
1032			Domain Administrators Guide				x								
1033			Domain Administrators Operations Guide				x								
1034	Standard		Domain Names – Concepts and Facilities	x		x	x			x	x	x			
1035	Standard		Domain Names – Implementation and Specification		x	x		x			x	x	x		
1101			DNS Encoding of Network Names and Other Types			x									
1123	Standard		Requirements for Internet Hosts – Application and Support	x							x	x			
1178	Informational		Choosing a Name for Your Computer				x								

DNS:
~143 active
RFCs

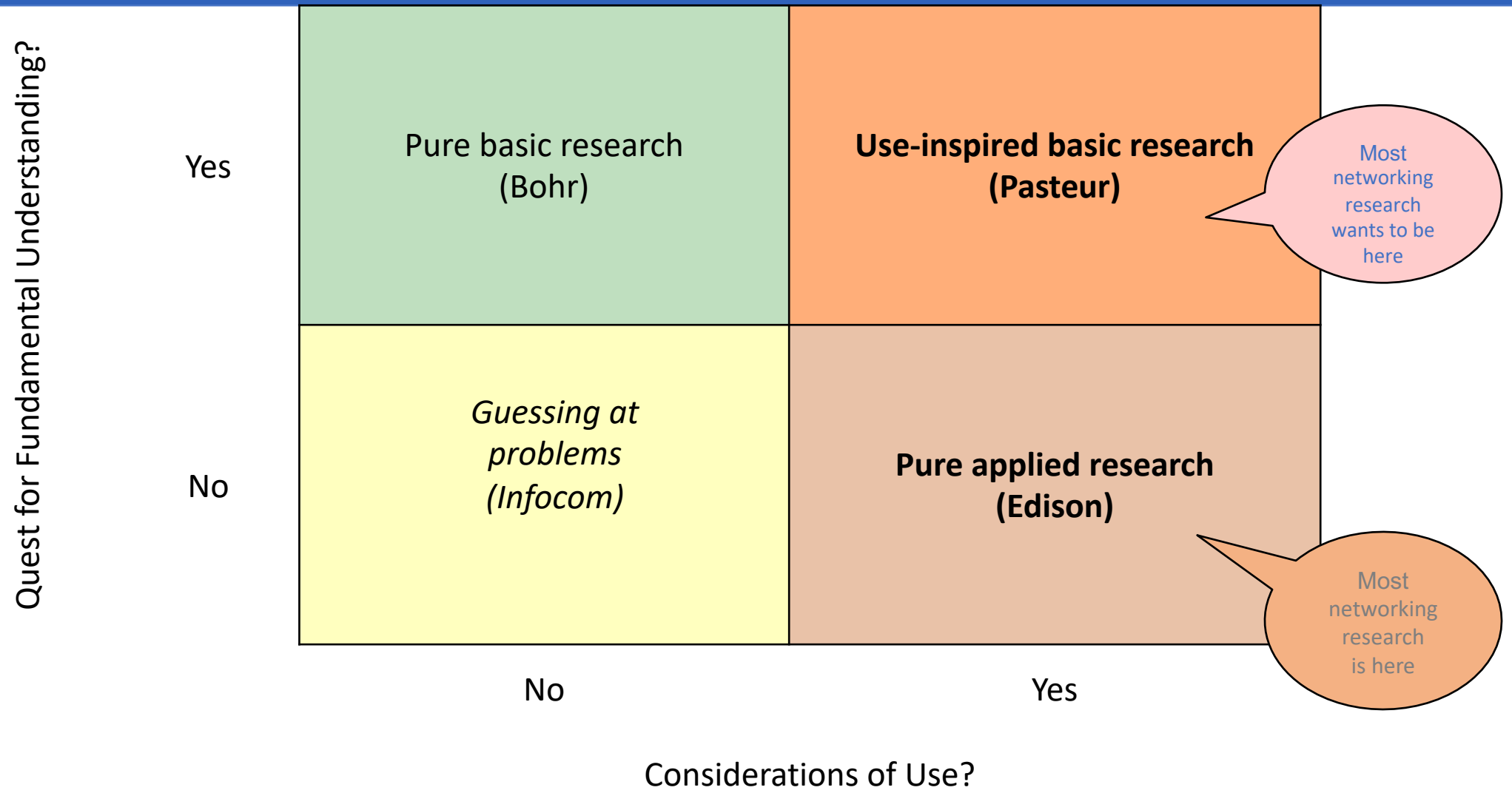
Publish it and they will implement

The universal equation for engineering

$$I = \lim_{t \to \infty} \frac{impact}{\log_{10} papers} = 0$$

impact factor, redefined: citations → real world

Research: Pasteur's quadrant



Pasteur's Quadrant: Basic Science and Technological Innovation, Stokes 1997 (modified)

Cause of death (or delay) for the next big thing

	QoS	multi-cast	mobile IP	active networks	IPsec	IPv6
not manageable across competing domains	✞	✞	✞	✞		
not configurable by normal users (or apps writers)	✞			✞	✞	
no business model for ISPs	✞	✞	✞	✞	✞	✞
no initial gain	✞	✞	✞	✞		✞
80% solution in existing system	✞	✞	✞	✞	✞	✞ (NAT)
increase system vulnerability	✞	✞	✞	✞		

Network layer minimalism wins

- Almost all attempts to add functionality to the network layer have been unsuccessful or multi-decade
- IPv6 [*1994] → NAT, CGN (despite address exhaustion)
- IP multicast, CCN → CDN
- IP QoS → FTTH
- network-layer security → TLS
- IP mobility → no mobile servers + rare IP address changes

Generational surprises

Generation	Expectation	Surprise	Cost per GB
0G (landline)	voice	fax & modem	
1G	corporate limousine	eavesdropping	
2G	better voice quality (“digital!”)	SMS	$1000
3G	WAP	web	$100
4G	IMS	YouTube, WhatsApp, notifications	$10
5G	IoT (low latency)	?	$1?

- underestimated cost and fixed-equivalence as drivers
- are the even generations the successful ones?

What makes the paper-to-product pipeline hard?

- Even highly cited papers rarely impact practice
  - and usually not useful as input into meta-studies (medicine)
  - many papers have more authors than readers
  - “You just published a paper and expect me to change the Internet?”
  - other disciplines: niche papers for niche problems
    - what are niche networks? We try…
- “standing on the shoulders of thousand midgets”

Paper-to-network transitions are difficult

Computer Networks
Volume 101, 4 June 2016, Pages 158-168

Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination (Article)

Wang, S., Wan, J., Zhang, D., Li, D., Zhang, C.

[a]School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou, China
[b]School of Software Engineering, Tongji University, Shanghai, China

Abstract

The proliferation of cyber-physical systems introduces the fourth stage of industrialization, commonly known as Industry 4.0. The vertical integration of various components inside a factory to implement a flexible and reconfigurable manufacturing

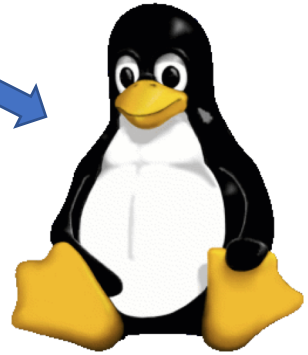
RFC Editor

The Series

Document Retrieval
Errata
FAQ
Future Format FAQ

The RFC series

contains technical and organizational documents about the Internet, including the specifications and policy documents produced by four streams: the Internet Engineering Task Force (IETF), the Internet Research Task Force (IRTF), the Internet Architecture Board (IAB), and Independent Submissions.

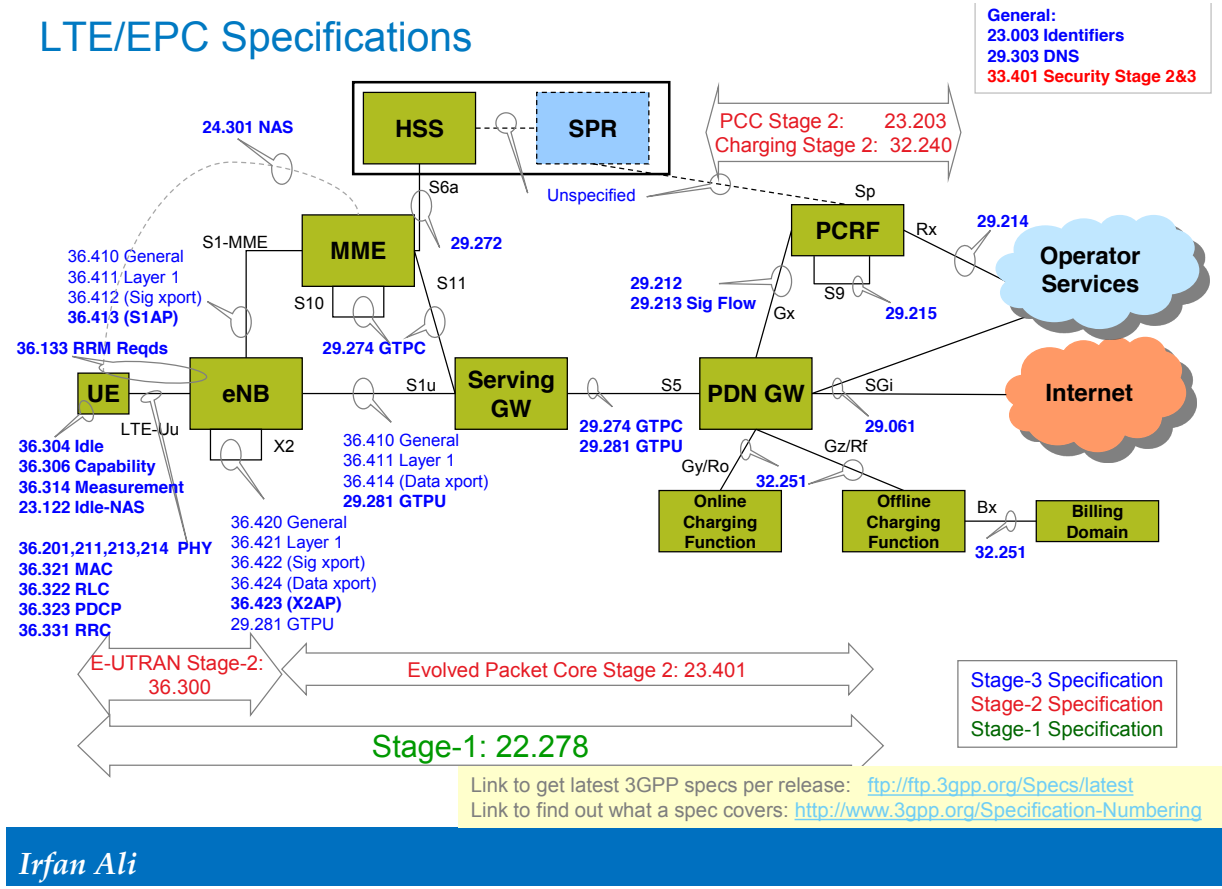


Google

The streetlight effect

||Wi-Fi|| >> ||LTE||

ORBIT, Rutgers

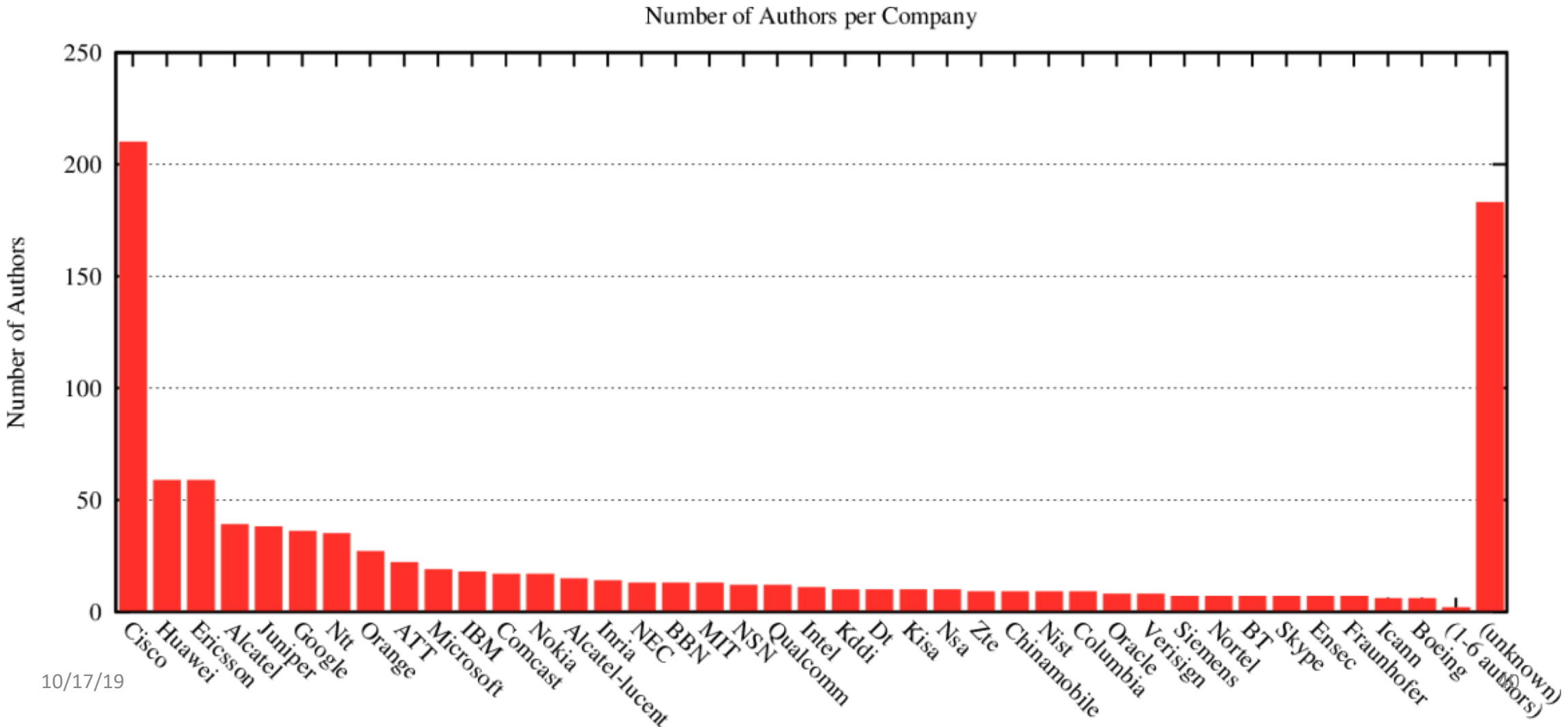


Funding agencies want broader impact, but don’t fund standards work

Translational activities as broader impact?

- RFCs may or may not count as publications
- Contributing to standards increasingly costly (travel, time)
- NSF may ”count”, but uncommon
- European projects seem to be more flexible

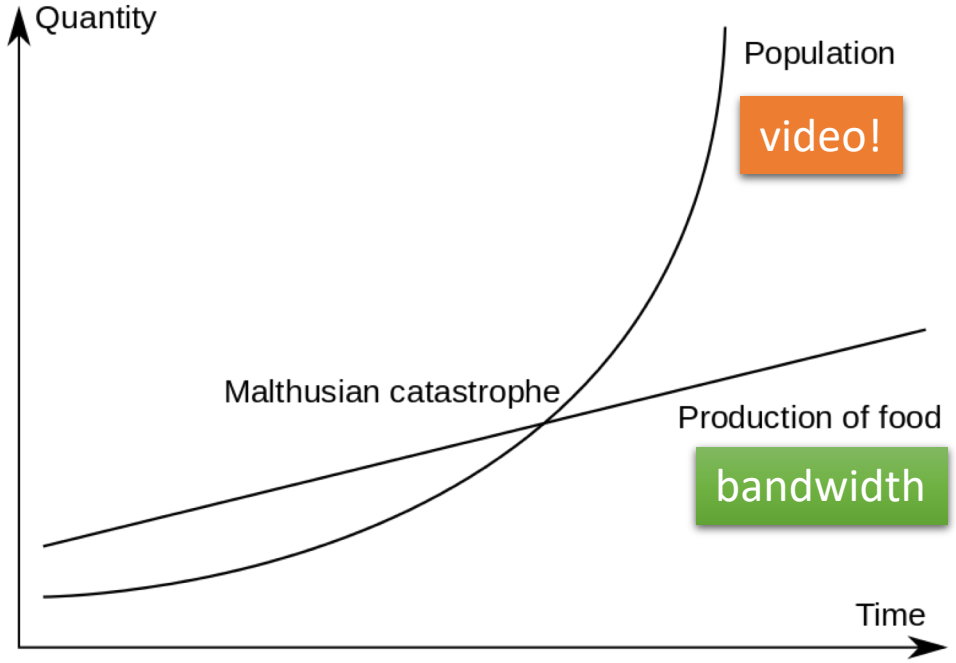
Standards contributions



Math hammers, looking for nails

History doesn’t repeat, but it rhymes

- Common theme
  - path finding (routing)
  - congestion control
  - scarcity of X → resource management
- Almost every quantitative & statistical technique
  - queueing theory
  - matrix methods
  - machine learning



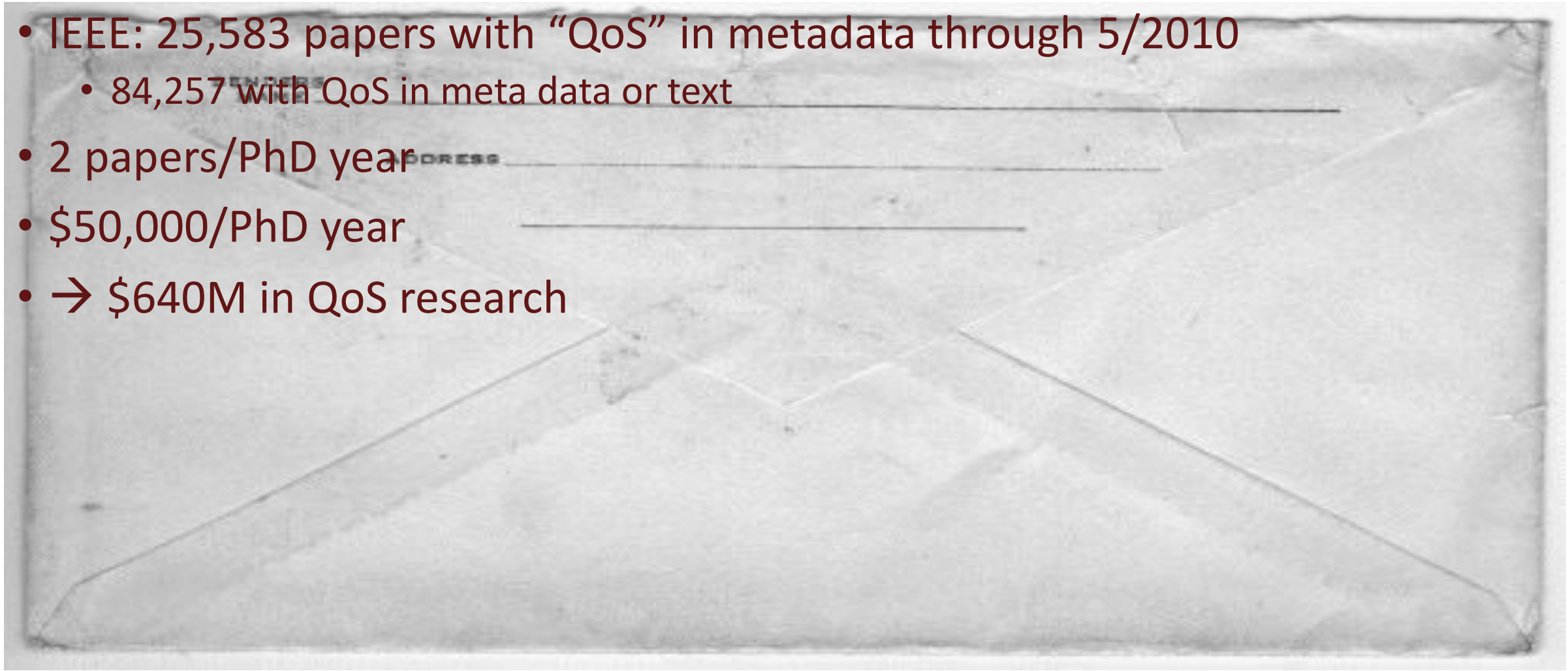
Almost ~~25~~100 years of QoS

Toll Telephone Traffic

Experiments are described to determine the relationship between telephone circuit loads and the corresponding delay to traffic. The operating methods employed and the number of circuits available determine in general the number of messages per day which can be handled over a single toll circuit. The average delay to traffic obviously depends upon the number of messages per circuit per day, or the circuit loads. With a given load factor, increase in the circuit loads will increase the average delay to traffic. At the same time the revenue per circuit mile will correspondingly increase. The practical limit, however, is approached when the delays to traffic reach a point where the service is unsatisfactory. The results of the experiments described illustrate the fact that increasing circuit loads increase the delay to traffic, and vice versa. The revenue per circuit mile is directly proportional to the product of the circuit load and the toll rate per minute-mile; consequently the relationship between the quality of service and the toll rate is generally obvious, assuming a certain rate of return on the plant investment.

Frank Fowle, *Transactions of the American Institute of Electrical Engineers*, June 1914

QoS research



- IEEE: 25,583 papers with “QoS” in metadata through 5/2010
  - 84,257 with QoS in meta data or text
- 2 papers/PhD year
- $50,000/PhD year
- → $640M in QoS research

Telecommunication carriers are like airlines

Equipment vendors & operators

commodity
(rarely loved, only hated less)

livery
advertising
pricing

BOEING AIRBUS

NOKIA ERICSSON HUAWEI

Boeing 737
designed 1967

INTERNET PROTOCOL

DARPA INTERNET PROGRAM

PROTOCOL SPECIFICATION

September 1981

UNITED 770-800

American Airlines

verizon

COMCAST

800 GSM operators

“We don’t want to be bit pipes”

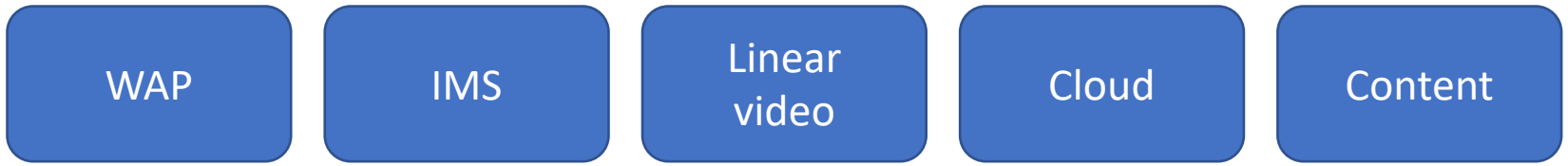
‘We don’t need your Internet. There is no way we can make money on it. We don’t want to be just dumb pipes!’

France Telecom
Minitel era (~2000)

→ Avoid commoditization (competition on price only)

Two mechanisms: provide better services vs. withhold services (”APIs”) or price-differentiate

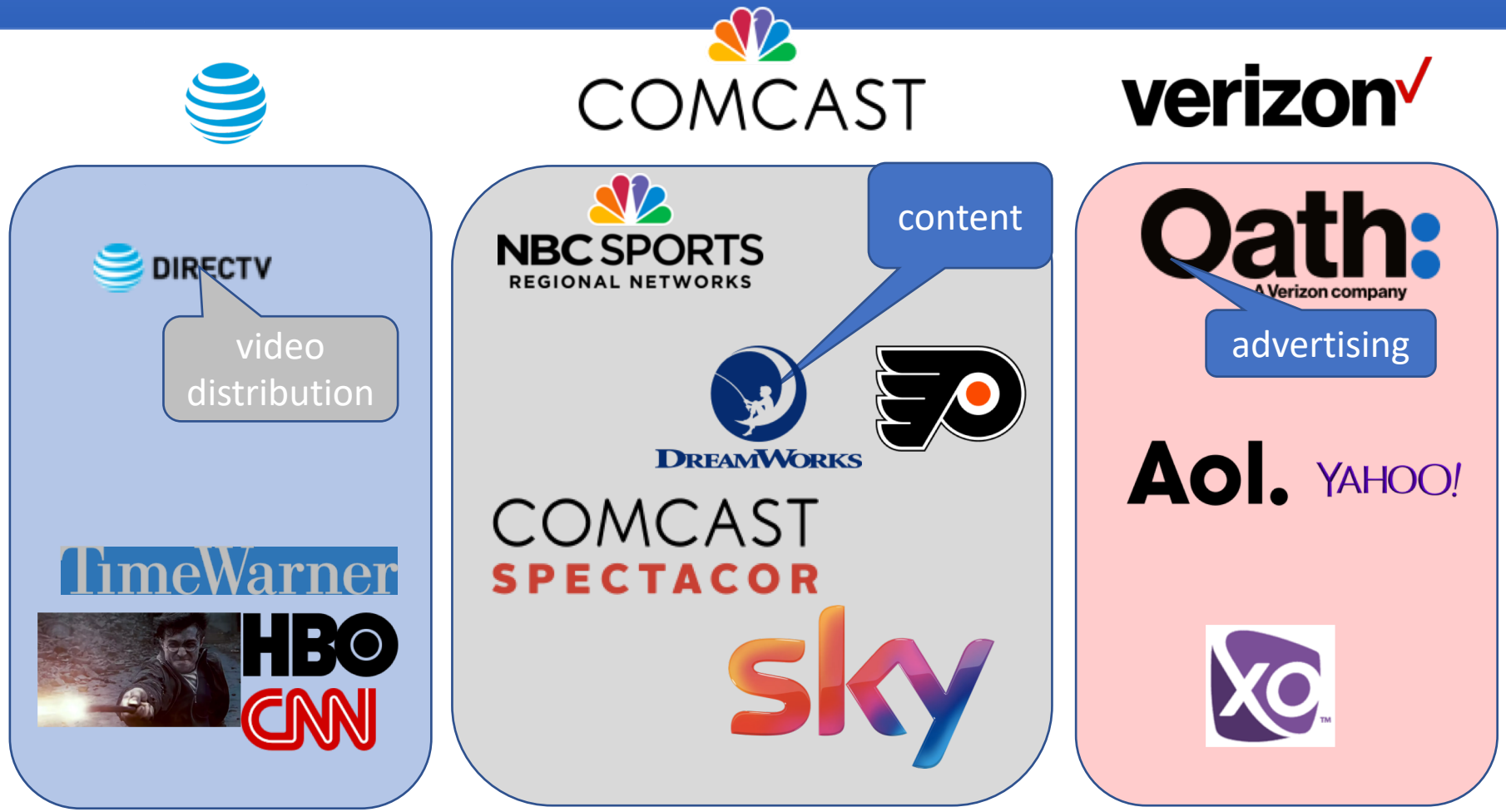
chief executive Arun Sarin who cautioned mobile carriers that “we must not allow ourselves to become bit-pipes and let somebody else do the services work.” 2008



Which prevents them from being *good* bit pipes

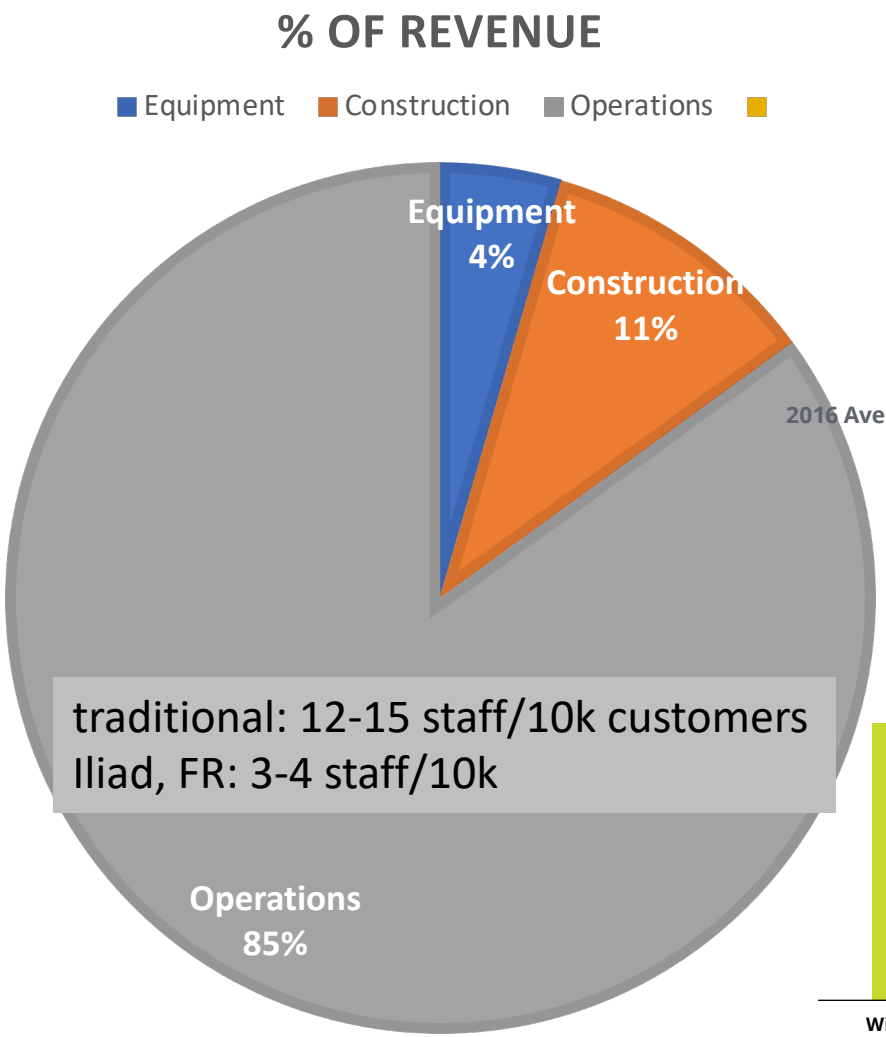
→ unusual, but inherent, conflict of interest between provider and customer

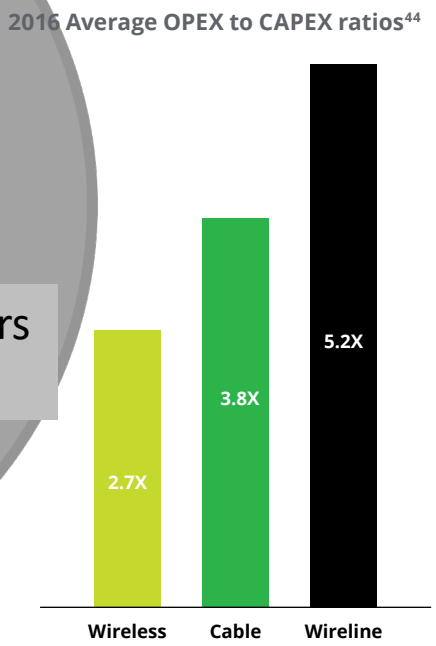
Networking companies don’t want to be



Bits, bytes and cycles are cheaper than humans

Network economics, (over)simplified





Which will be autonomous first?

The Zero-Person Network Operations Center Is Here (in Finland)

NEWS ANALYSIS
IAIN MORRIS,
News Editor

3/23/2018

COMMENT (0)

Login

50% 50%

Telecom engineers continue to make speedy progress on phasing themselves out of the workforce, with the revelation this week that Elisa, Finland's biggest mobile operator, is now operating a zero-person network operations center (NOC).

The absence of humans has been well received by other humans, it seems. Customer complaints are down 15% since Elisa Corp. fully automated the NOC. And the number of "incidents" (macchiato spilt on circuitry, perhaps) has fallen 50%.

Elisa began automating its systems nearly a decade ago to cope with surging levels of mobile traffic. It recently began selling its automation tools and expertise to other operators, as Light Reading reported earlier this month. (See Finland's Elisa Is Selling Its Automation Smarts to Other Telcos.)

But the news that its NOC is an entirely human-free zone was met with surprise at this week's Zero Touch & Carrier Automation Congress in Madrid. While some other telco facilities have been unmanned for a long time, the NOC has been the one place where people still keep an eye on the machines.

Automation & NFV

On the networks side, too, Deutsche Telekom has made automation a priority in the last few months. Last October, its deputy chief technology officer, Arash Ashouriha, said his ultimate goal was to develop networks that could function without people. "We now have a vision of zero-touch network service management with no human involvement," he told an industry conference in The Hague. "Brutal automation" is the only way to go, he said. (See DT: Brutal

	Total headcount	Job cuts announced	Cuts as percentage of workforce	Per-employee revenues ($) in 2016 fiscal year	Per-employee revenues in ($) 2017 fiscal year
BT	105,800	13,000	12.3%	305,010	301,649
CenturyLink	51,000	1,000	2.0%	N/A	N/A
Deutsche Telekom	217,349	10,000	4.6%	396,166	407,774
Telecom Italia	59,429	4,500	7.6%	310,310	333,171
Telstra	32,000	8,000	25.0%	N/A	N/A
Total	465,578	36,500	7.8%	N/A	N/A

Source: Operators, Light Reading.

The operator is lagging targets partly, it seems, because high software licensing and maintenance charges have wiped out savings on the hardware side. "We've dropped the price of hardware to a seventh but if you are adding to the price of software licenses you are not where you need to be," he says.

The other problem for Telus has been the increase in complexity that NFV has initially brought. Instead of allowing it to reduce employee numbers through automation, virtualization has led to an increase in the size of the operations team at the Canadian operator.

"We may cripple ourselves with NFV because we have double the teams now," says Gedeon. "We have the NFV teams as well."

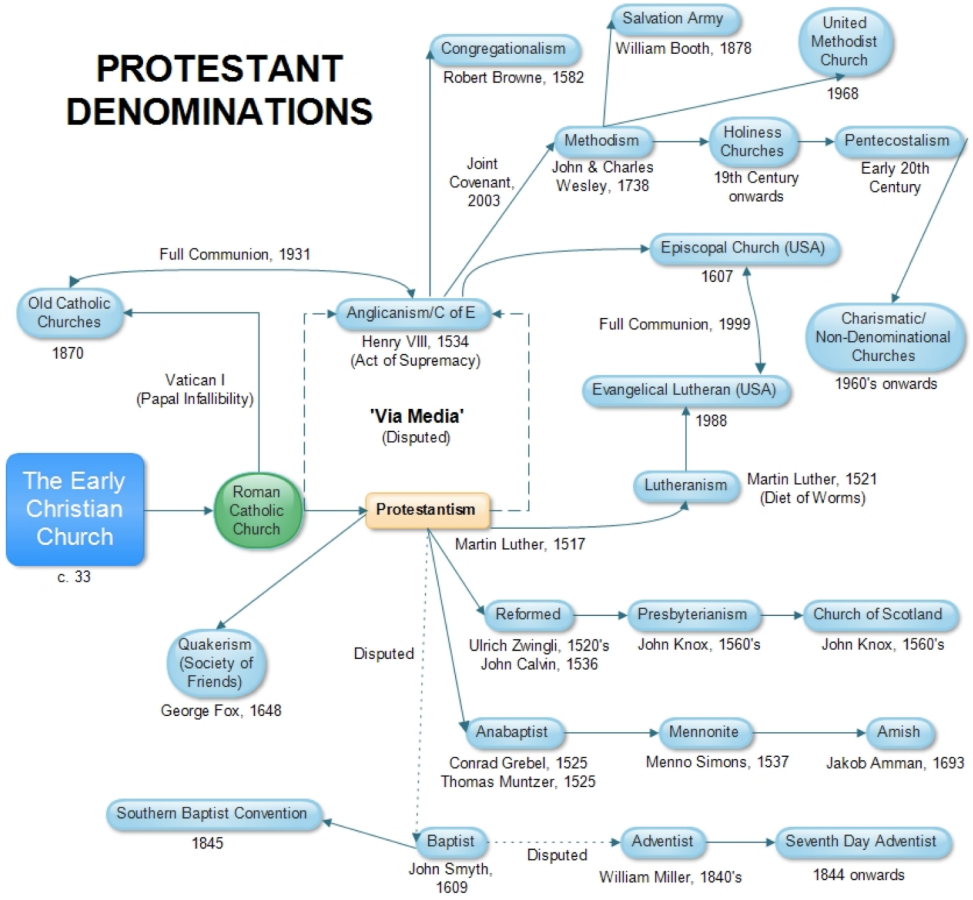
The situation is pressing because costs per bit are not dropping as fast as revenues per bit, says Gedeon, who delivers a scathing verdict on some of the mainstream vendors that serve his business. (See Nolle: In 2017, Cost Per Bit Exceeds Revenues.)

We do not consider cost (enough)

- Most engineering is cost minimization, given constraints
- But hard for networking
  - cost data not available (proprietary)
  - very little economics in our network teaching
  - improvements are in operations and management more than protocols and algorithms
- Would require better software skills in carrier work force
  - and willingness to develop own software
  - and get rid of legacy systems and services

Statements of faith

We have fashions and movements



OSI (vs. IP)

blockchain

CCN

ATM

text vs. binary

machine learning

sensor networks

IoT

5G

NAT vs. IPv6

5G – the next moonshot

- “5G could be one of the great moonshots of this generation” (FCC Chairman Pai, July 2019)
- “And because many of the game-changing applications of 5G have not yet been invented or even imagined, we will certainly run into skeptics who think this will be useful for nothing more than faster downloads of movies or cat videos to our phones.” (same)
- ”Secure 5G networks will absolutely be a vital link to America’s prosperity and national security in the 21st century. 5G will be as much as 100 times faster than the current 4G cellular networks. It will transform the way our citizens work, learn, communicate, and travel. It will make American farms more productive, American manufacturing more competitive, and American healthcare better and more accessible. Basically, it covers almost everything, when you get right down to it. Pretty amazing.” (your guess)

Our version of history telling

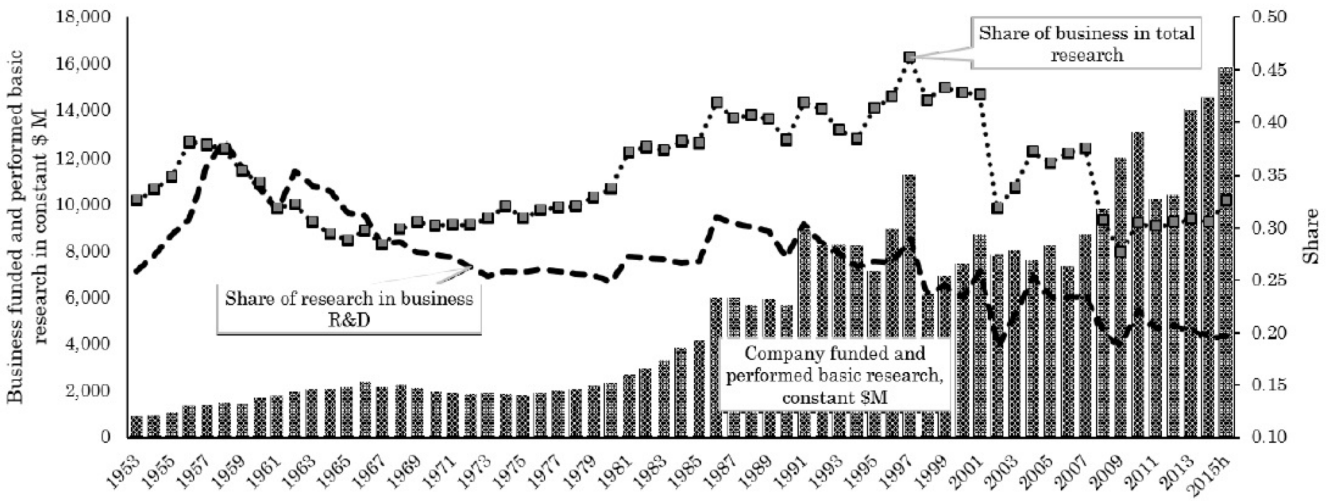
While ATM did not live up to every expectation, i

Industrial research is a monopoly game

Only monopolists with patient shareholders do research

From the early years of the twentieth century up to the early 1980s, large corporate labs such as AT&T's Bell Labs, Xerox's Palo Alto Research Center, IBM's Watson Labs, and DuPont's Purity Hall were responsible for some of the most consequential inventions of the century such as the transistor, cellular communication, graphical user interface, optical bers, and a host of synthetic materials such as nylon, neoprene, and cellophane.

Figure 2: BUSINESS FUNDED AND PERFORMED RESEARCH IN THE UNITED STATES, 1953-2015

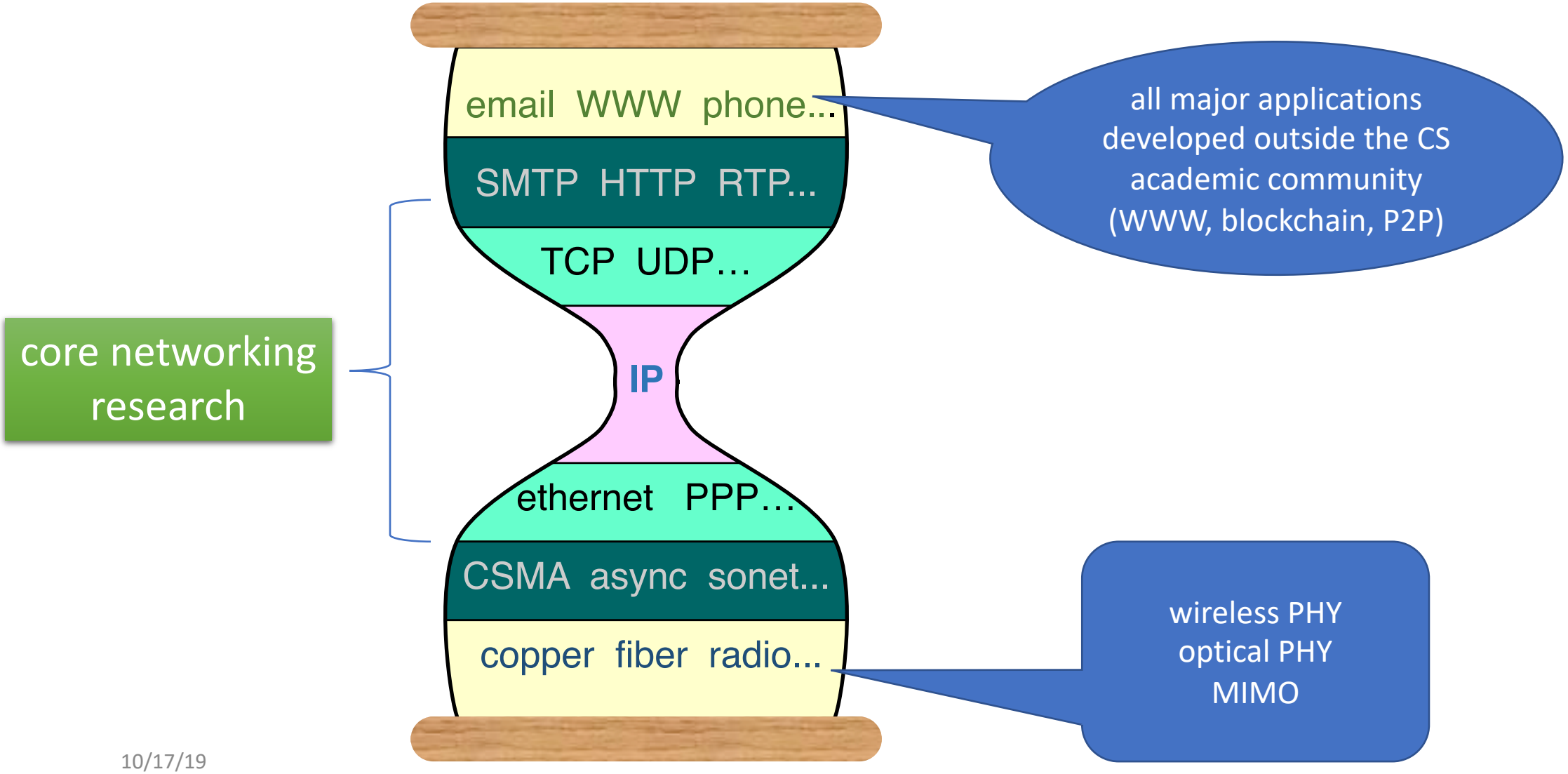


Notes: Data for this graph is sourced from the *National Patterns of R&D Resources: 2014-15 Data update. NSF 17-311.* from the National Science Foundation, National Center for Science and Engineering Statistics. 2017. Arlington, VA. Available at https://www.nsf.gov/statistics/2017/nsf17311/.

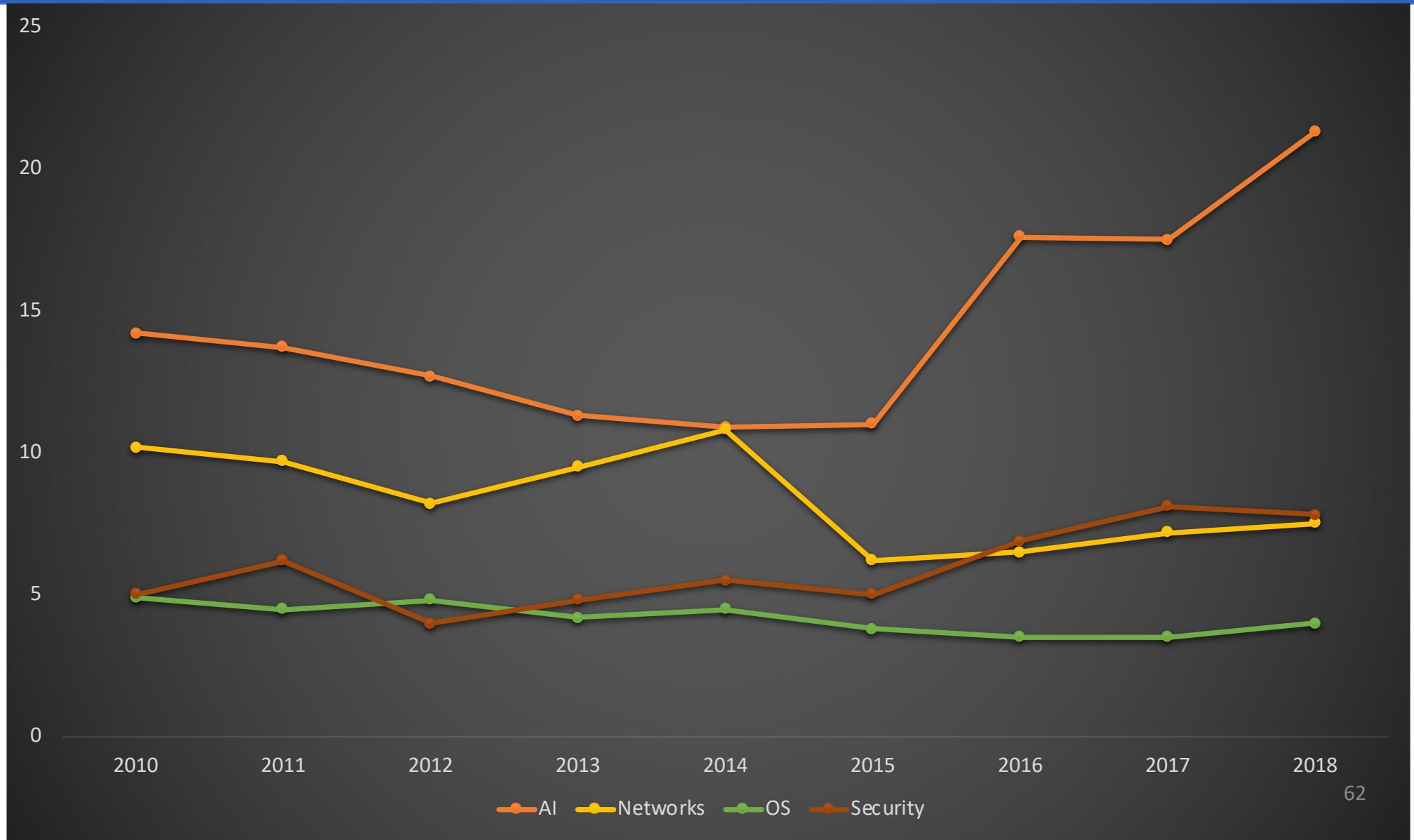
non-networking relatives may survive

Stuck in the middle

Depending on those above and below



PhD students are our future



Sensor networks optimized the wrong thing

28 EU projects

SENSORS AND SENSOR NETWORKS

PROGRAM SOLICITATION
NSF 03-512

- Most IoT systems will be near power since they'll interact with energy-based systems (lights, motors, vehicles)
- Most IoT systems will **not** be running TinyOS (or similar)
- Protocol processing overhead is unlikely to matter
- Low message volume → cryptography overhead is unlikely to matter
  - exceptions: light switches and similar 1-function I/O devices → BT/Zigbee fixed-function devices

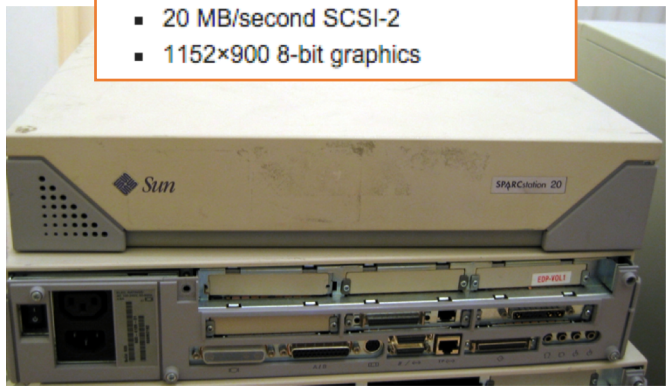
In particular, according to the indexes, a Raspberry Pi is about **seven** times as fast as a baseline SPARCstation 20 model 61 — and has substantially more RAM and storage, too. And the Raspberry Pi 2 is **sixteen times** as fast at single-threaded tasks, and on tasks where all cores can be put to use it's **forty one times** faster.

$35.00

- A 900MHz quad-core ARM Cortex-A7
- 1 GB RAM

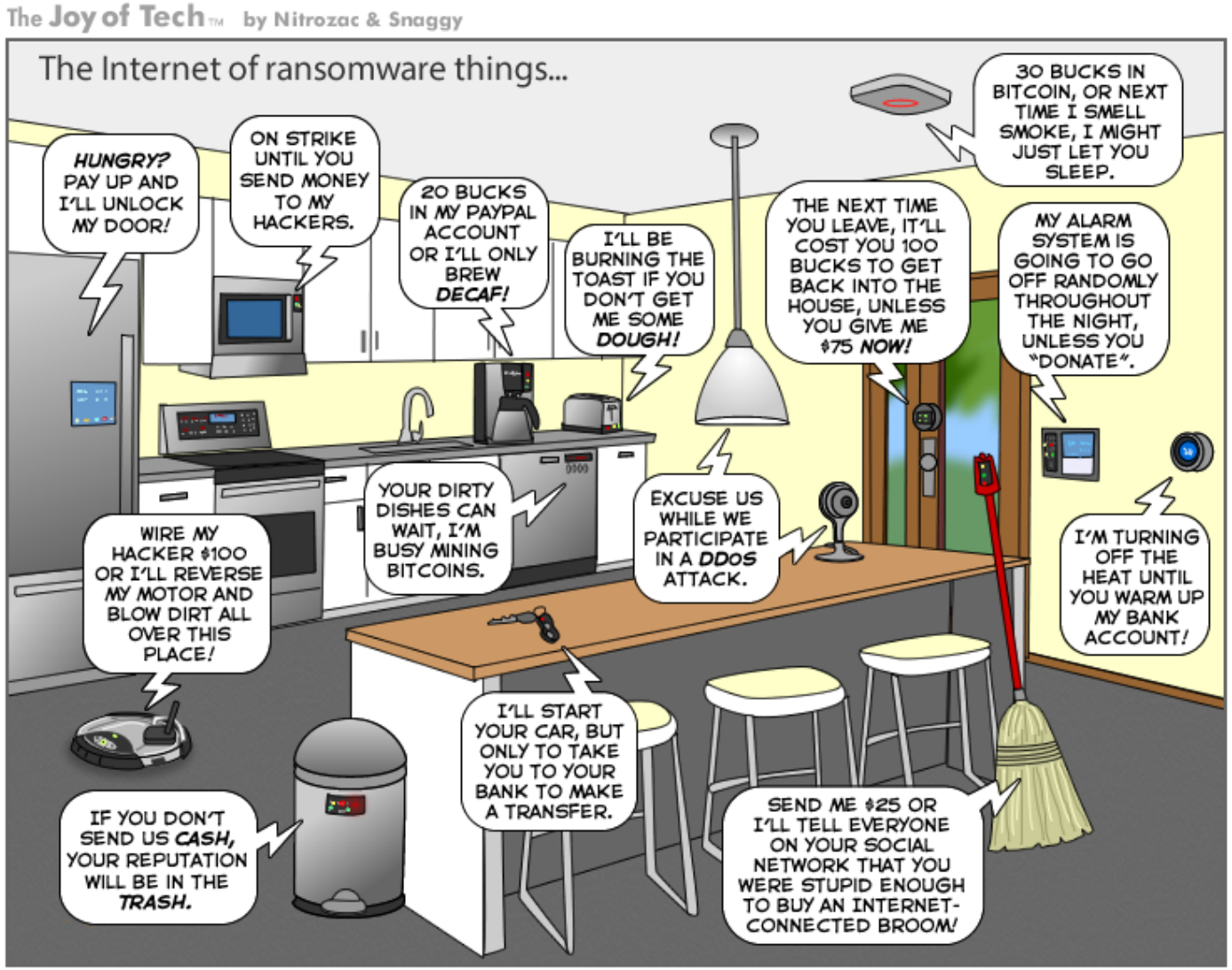
16-41x

- One 60 MHz SuperSPARC CPU
- 1 MB of cache
- 32MB RAM (expandable to 512MB)
- 20 MB/second SCSI-2
- 1152×900 8-bit graphics



http://eschatologist.net/blog/?p=266

But (largely) ignored user concerns



Moving up (and down)

privacy → data usage
cyber security
network neutrality
news, real & fake

5G, 6G, …
quantum communications

You cannot replicate yourself to funding or tenure

Good intentions, bad incentives

The Dagstuhl Beginners Guide to Reproducibility for Experimental Networking Research

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Many high-profile measurement projects rely on “secret” data

Reproducing results is only likely to occur if somebody really cares about the result.

Resource scarcity, the money part

Money sources

1980-2000s

industry

NSF

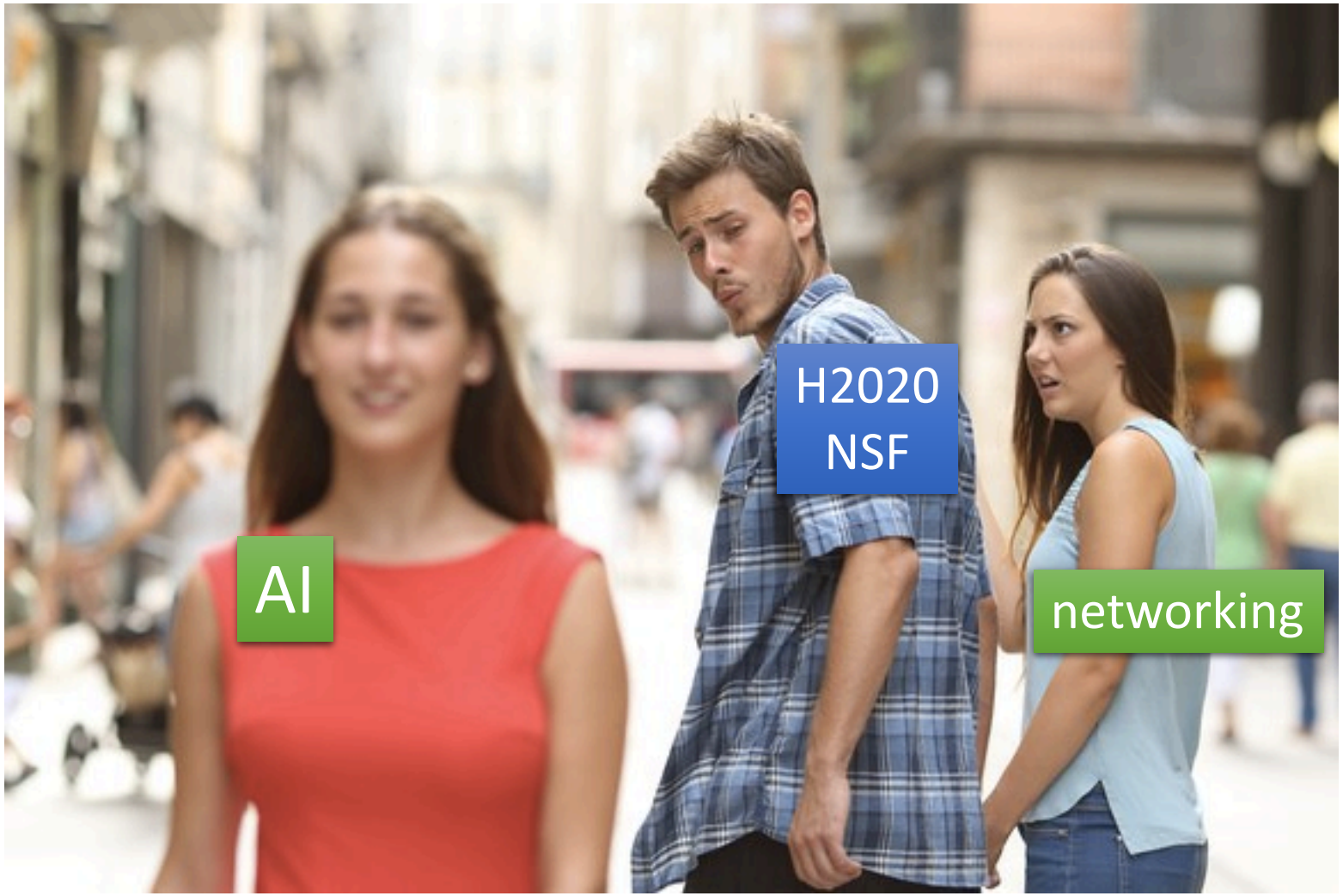
DARPA

now

NSF
$14.4M/year

➔ *networking for X*

I know how you feel…

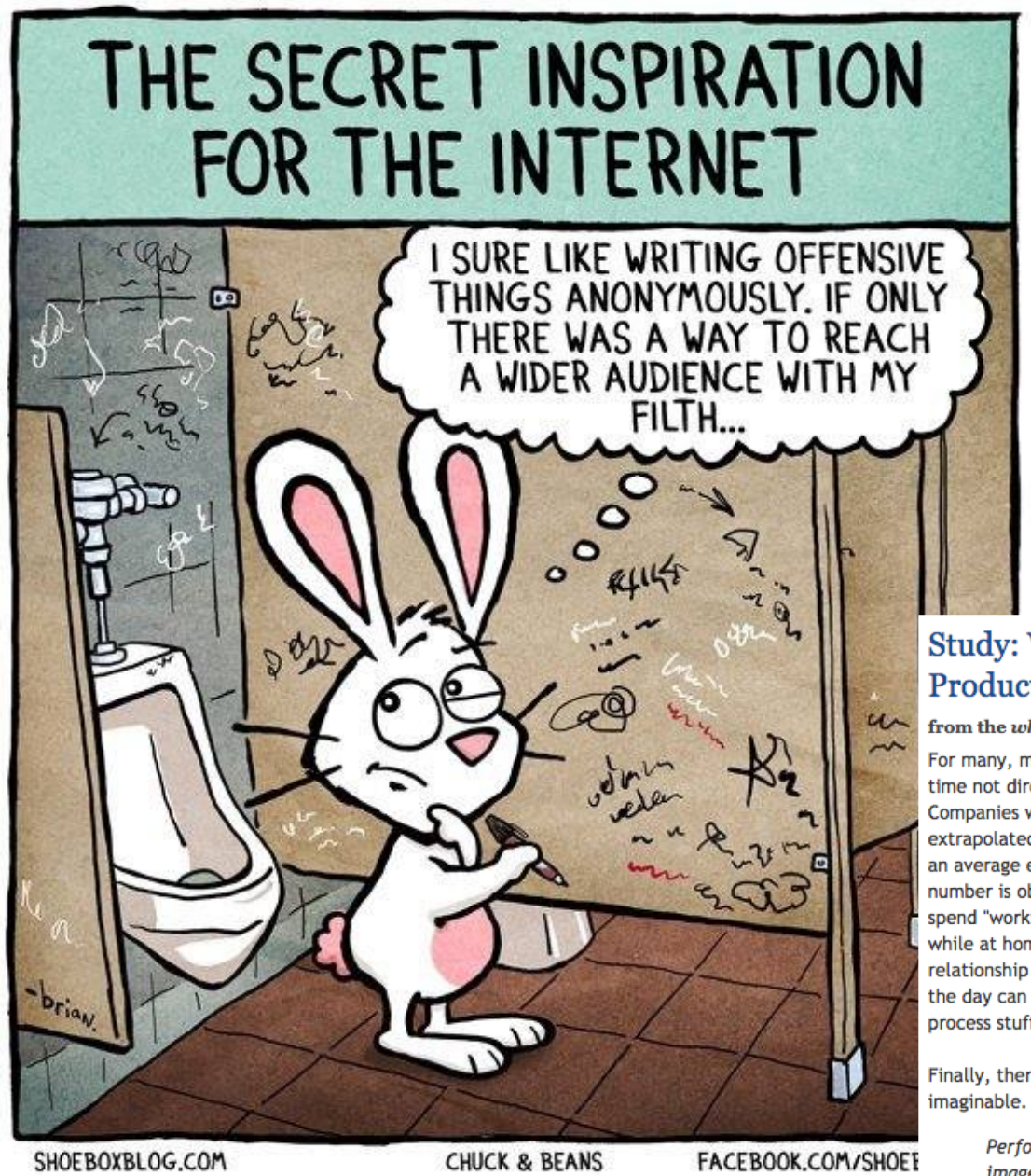


The internet is not meant to be secure

Security is an incentives problem

- “Making the Internet secure” assumes that this is a layer-3 problem
- But identity and intent reside higher in the stack
- Encryption helps only because networks are now untrustworthy
- Internet has an *identity* problem, not a (generic) security problem
- Struggling to implement network hygiene:
  - BCP 38 (address spoofing)
  - DNSSEC (domain spoofing)
  - MANRS, RPKI (route spoofing)
  - STIR/SHAKEN (phone number spoofing)

Connectivity is not good



Study: Viewing Cat Videos At Work Can Make You More Productive

from the *who-comes-up-with-these?* dept

For many, many years, we've pointed out just how silly all those studies are that claim that any time not directly spent working -- such as on "**personal surfing**" -- was somehow lost productivity. Companies who sold filters to businesses often would put out these exaggerated "studies" that extrapolated the amount of time that people spend doing "non-work" things at work, multiply it by an average employee's hourly salary, and claim that much money was "lost productivity." That number is obviously bogus. First of all, it doesn't take into account the amount of time people spend "working" when they're not at the office either (many of us check our emails, for example, while at home). It also ignores the much more important point that productivity is not an exact relationship to time worked in many jobs. In fact, being non-stop focused on work every minute of the day can certainly be a *drag* on productivity, because it doesn't give your brain time off to process stuff, and doesn't give you a good way to focus in on what you need to do.

Finally, there's a study to help point this out... and it does so in the most internet-awesome way imaginable. The study has found that **staring at cute images can actually *help* productivity:**

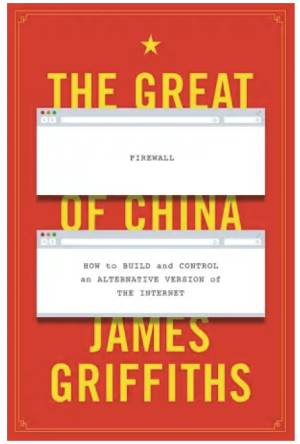
> *Performance indexed by the number of successful trials increased after viewing cute images (puppies and kittens; M ± SE = 43.9±10.3% improvement) more than after viewing images that were less cute (dogs and cats; 11.9±5.5% improvement). In the*

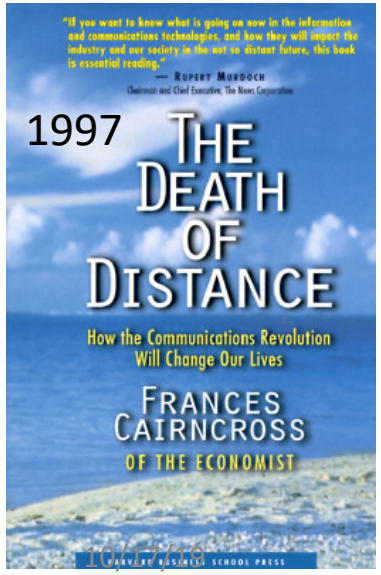
A Declaration of the Independence of Cyberspace

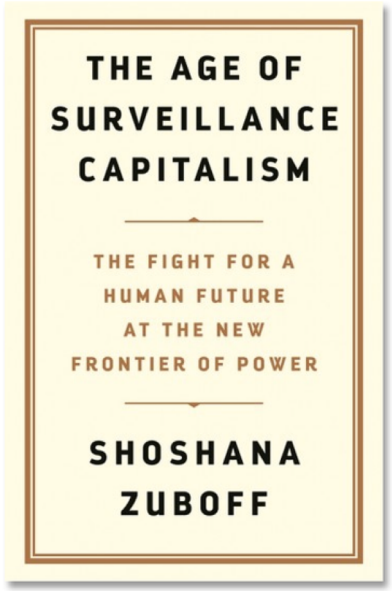
1996

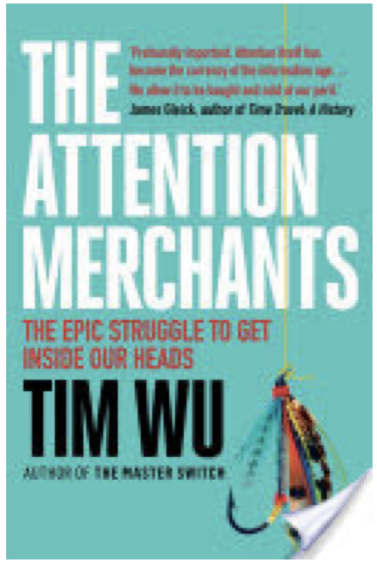
by John Perry Barlow

Governments of the Industrial World, you weary giants of flesh and steel, I come from Cyberspace, the new home of Mind. On behalf of the future, I ask you of the past to leave us alone. You are not welcome among us. You have no sovereignty where we gather.









chan

5G: all the credit, none of the blame

- Typical argument:
  - we have a problem ∈ {competitiveness, aging society, traffic accidents, climate change}
  - IT can play some role in ameliorating the problem
  - IT needs networks
  - 5G is a new network technology
  - thus, 5G fixes problem!
- But
  - is 5G critical for the particular application?
  - or is it just connectivity – Wi-Fi, fiber, LoRa, satellite?
  - how large is the impact – broadband impact studies often inconclusive
- 5G as innocent technology: somehow doesn't facilitate all the connectivity-related problems
  - privacy, online crime, IoT attacks, election manipulation, …
  - all the credit, none of the blame

Making networks smaller → application TTL

WhatsApp limits message forwarding in fight against misinformation

By Jacob Kastrenakes | @jake_k | Jan 21, 2019, 10:15am EST

SHARE

Photo by Amelia Holowaty Krales / The Verge

WhatsApp will now limit users to forwarding a message only five times, in an attempt to cut down on the spread of misinformation. According to *Reuters*, the five time forwarding limit is being implemented across the world starting today.

The future is …

We're not done yet

- Internet = electricity or Metro: only discussed if unreliable
- Limited increase in user-visible speeds – variable, instead of fixed
- Finally self-managing networks?
  - but ping + reboot have survived 40 years…
- End of Moore's Law → specialized hardware for most functions
- Increasing system and component complexity → ever harder for researchers to contribute (except measure)
- New upper-layer services: P2P storage → block chain → ?
- Data privacy (data minimization) → data usage protections (hopefully) – data fiduciary
- Networks as enablers for everything, not necessarily as object itself
- One of the most powerful amplification tools, but limited influence on use

We will still be reviewing QoS papers

Learning from the past

- Underestimating adversaries
- Underestimating greed
  - privacy, lack of security progress
- Underestimating hardware (and PHY) progress
  - QoS, sensor networks, ATM, DQDB
- Believing (or fostering) hype
- But not asking “Why did X not live up to expectations?”
  - Are there lessons for future research
- Falling back on the same tropes
  - “QoS for X” & “Y for QoS” (ATM, IP, cloud, blockchain)

In this paper, we propose a new Cloud architecture for Container Image (CI) management containing a Web based Video-Conferencing (VC) application that assures high QoS and exploits the benefits of the Blockchain technology as a key component that differs from other existing solutions. Some key technologies, such as SCs,

Two visions for the future of networking

Civil engineering

- Automation
- Increased reliability
- Safety
- ”Connecting the world”
- Measurement
- Evaluation (“anti-marketing”)

Network thinking

- Layering
- Robustness to failures
- Evolvable technology
- Performance modeling (?)
- Governance