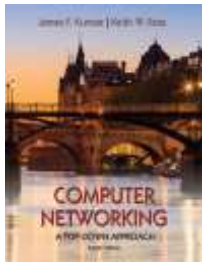
# Introduction

COMPSCI 453 Computer Networks
Professor Jim Kurose
College of Information and Computer Sciences
University of Massachusetts

- Overview. What *is* the Internet? What *is* a protocol?
- Network edge
- Network core
- Performance: loss, delay, throughput
- Layering, encapsulation, service models
- Networks under attack
- History

Class textbook:
*Computer Networking: A Top-Down Approach (8th ed.)*
J.F. Kurose, K.W. Ross
Pearson, 2020
http://gaia.cs.umass.edu/kurose_ross



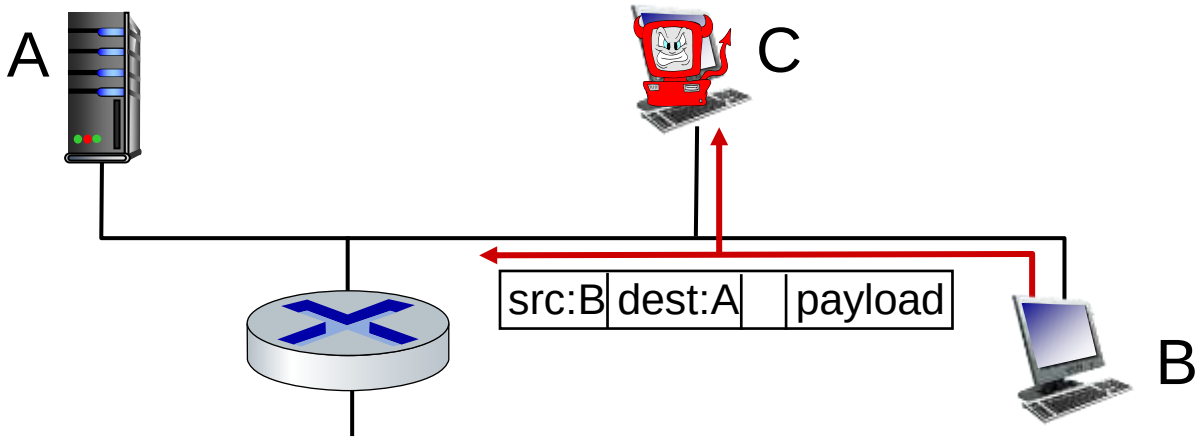
# Network security

- Internet not originally designed with (much) security in mind
  - *original vision:* "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - security considerations in all layers!
- We now need to think about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

# Bad guys: packet interception

*packet "sniffing":*

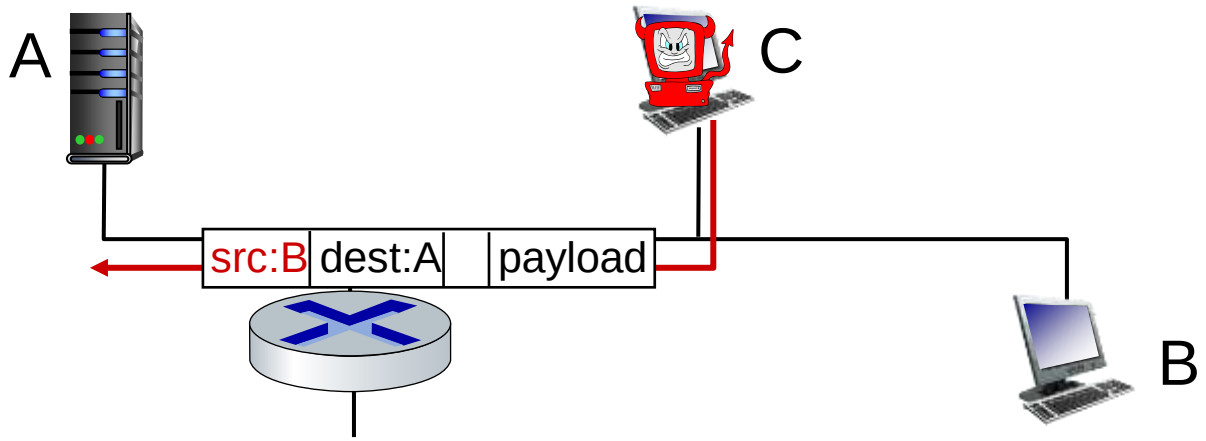
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by




Wireshark software used for our end-of-chapter labs is a (free) packet-sniffer

# Bad guys: fake identity

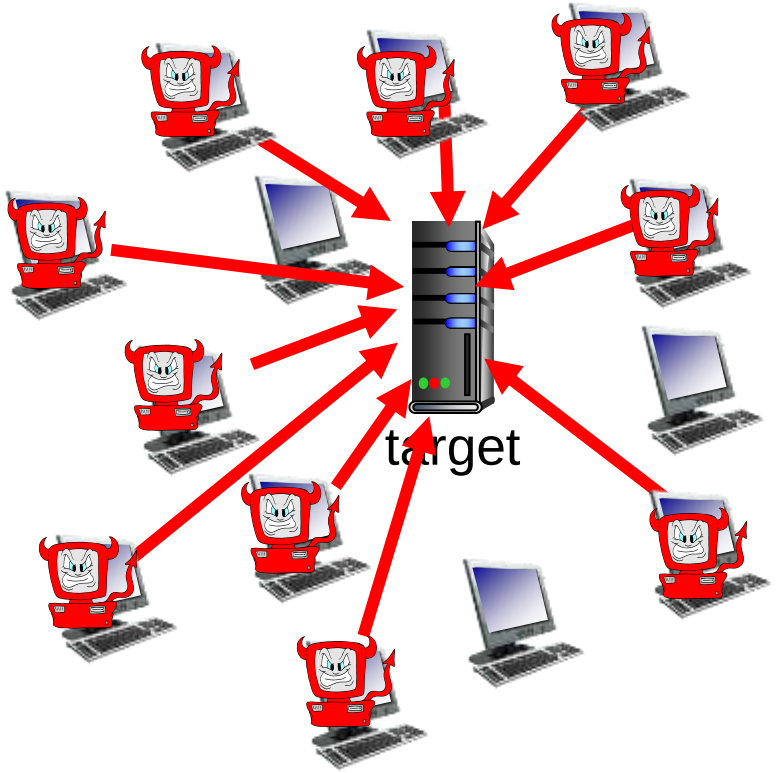
*IP spoofing:* injection of packet with false source address



# Bad guys: denial of service

*Denial of Service (DoS):* attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



# Lines of defense:

- authentication: proving you are who you say you are
  - cellular networks provides hardware identity via SIM card; no such hardware assist in traditional Internet
- confidentiality: via encryption
- integrity checks: digital signatures prevent/detect tampering
- access restrictions: password-protected VPNs
- firewalls: specialized "middleboxes" in access and core networks:
  - off-by-default: filter incoming packets to restrict senders, receivers, applications
  - detecting/reacting to DOS attacks

*… lots more on security (throughout, Chapter 8)*

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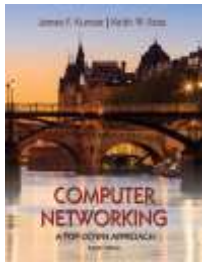

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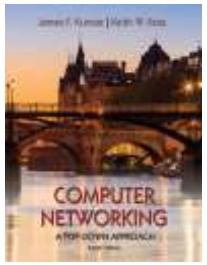
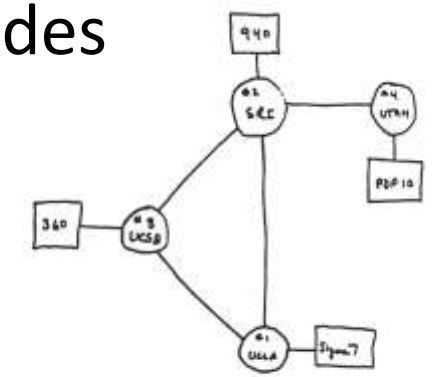


# Internet history

## *1961-1972: Early packet-switching principles*

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

# Internet history

## *1972-1980: Internetworking, new and proprietary networks*

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70's: proprietary architectures: DECnet, SNA, XNA
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best-effort service model
- stateless routing
- decentralized control

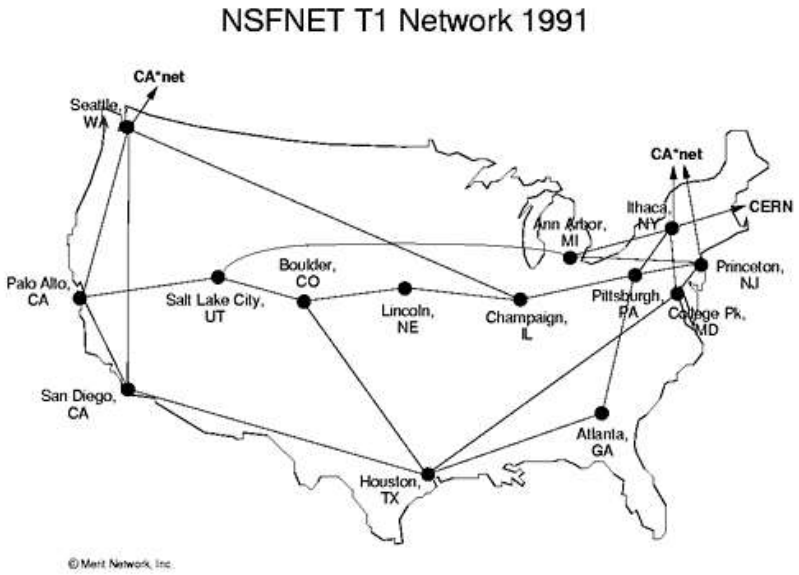
define today's Internet architecture

# Internet history

## *1980-1990: new protocols, a proliferation of networks*

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control

- new national networks: CSnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks



# Internet history

*1990, 2000s: commercialization, the Web, new applications*

- early 1990s: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990s: commercialization of the Web

late 1990s – 2000s:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

# Internet history

## *2005-present: scale, SDN, mobility, cloud*

- aggressive deployment of broadband home access (10-100's Mbps)
- 2008: software-defined networking (SDN)
- increasing ubiquity of high-speed wireless access: 4G/5G, WiFi
- service providers (Google, FB, Microsoft) create their own networks
  - bypass commercial Internet to connect "close" to end user, providing "instantaneous" access to social media, search, video content, …
- enterprises run their services in "cloud" (e.g., Amazon Web Services, Microsoft Azure)
- rise of smartphones: more mobile than fixed devices on Internet (2017)
- ~18B devices attached to Internet (2017)

# Chapter 1: summary

*We've covered a "ton" of material!*

- Internet overview
- what's a protocol?
- network edge, access network, core
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service , encapsulation
- networks under attack
- history

*You now have:*

- context, overview, vocabulary, "feel" of networking
- more depth, detail, *and fun* to follow*!*

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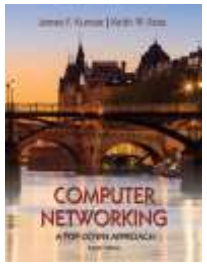

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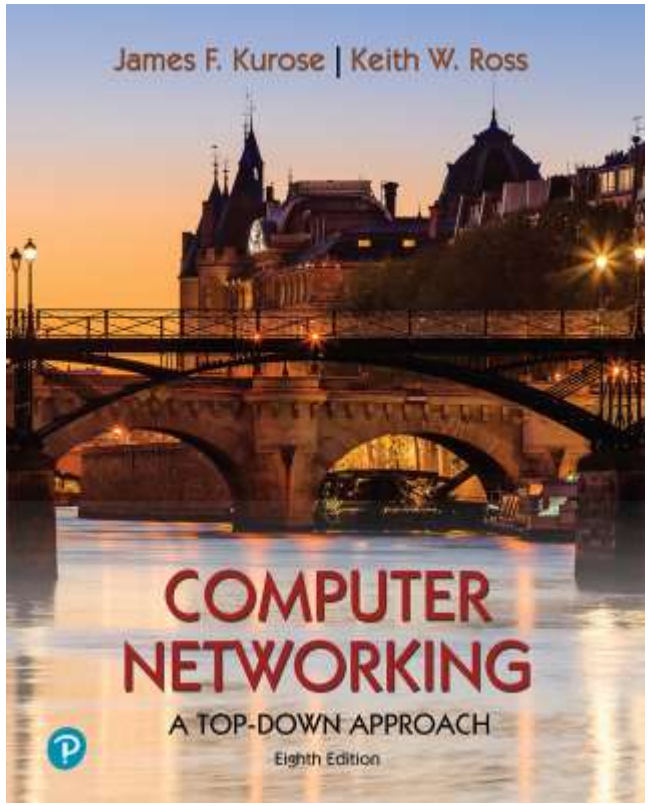


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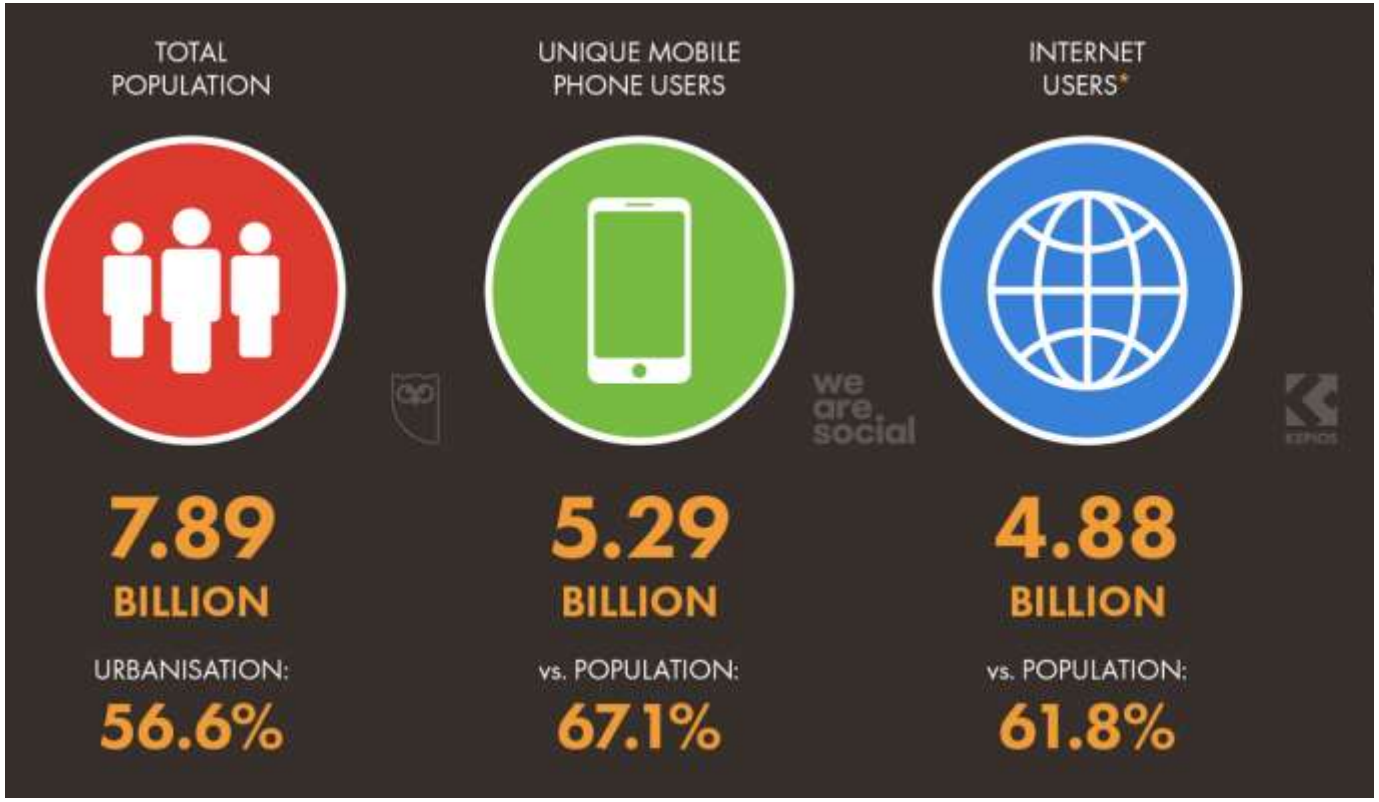
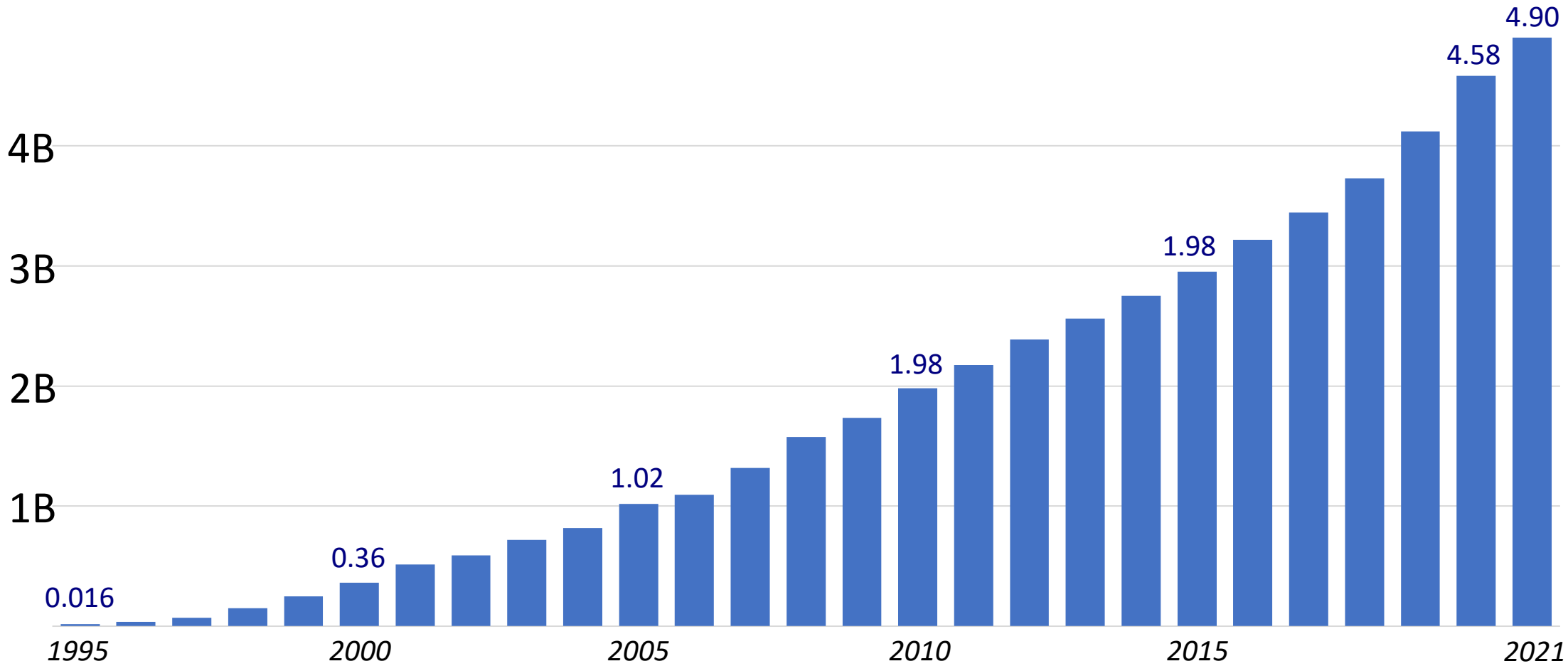
# “Who uses the Internet?”

2021 snapshot: global Internet/mobile connectivity:



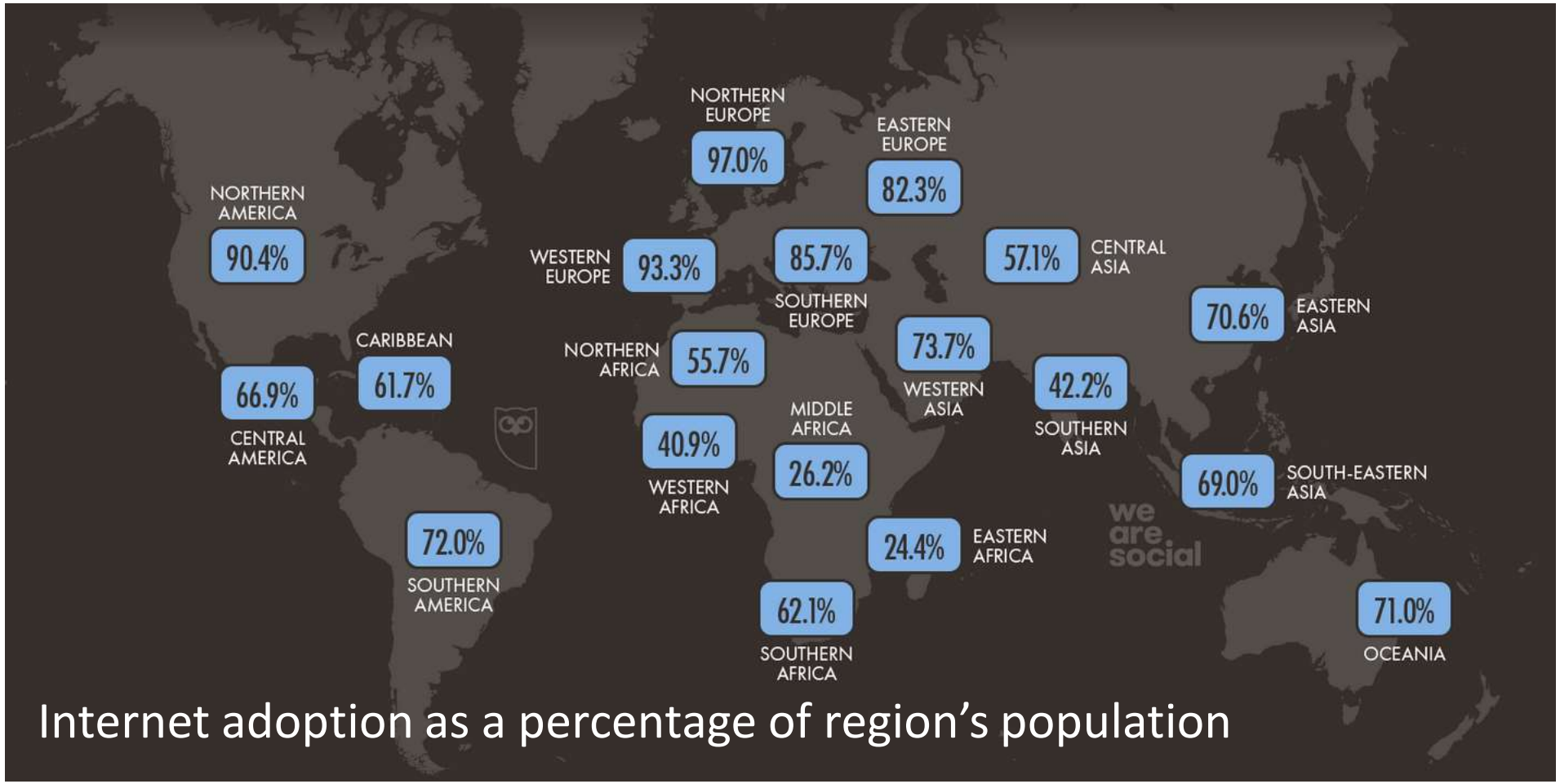

Oct. 2021, Source: http://datareportal.com/reports/a-decade-in-digital

# Number of global Internet users (over time)



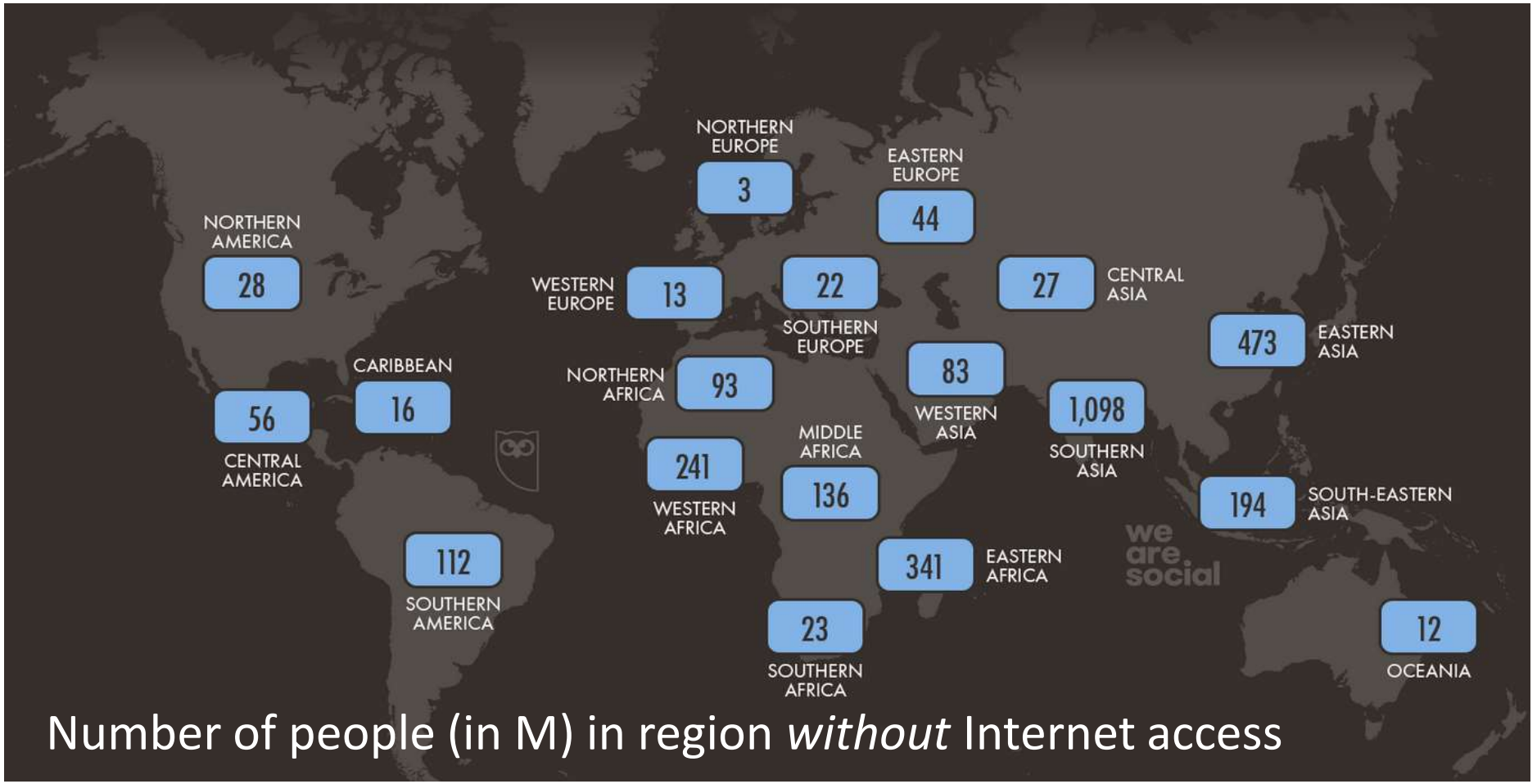

Sources: https://www.itu.int/en/ITU-D/Statistics/Pages/stat/

# Internet/mobile adoption, by region




April 2021, Source: https://datareportal.com/reports/6-in-10-people-around-the-world-now-use-the-internet

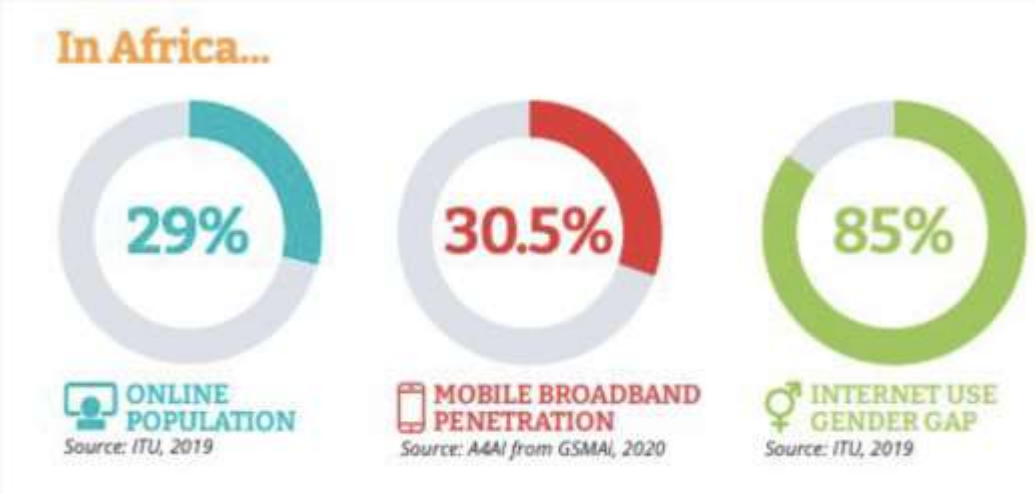
# Internet/mobile adoption: the missing 3B




Nov. 2021, Source: http://datareportal.com/reports/a-decade-in-digital

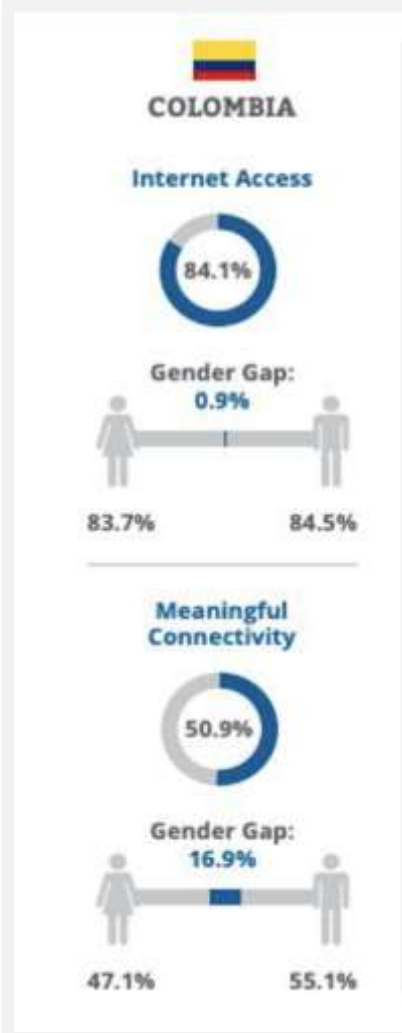
# Beyond “Connectivity”

Looking beyond “connectivity” to meaningful connectivity, affordability, gender disparities, and more...




43 out of 95 countries met “1 for 2” affordability target: 1GB for 2% or less of average monthly income.

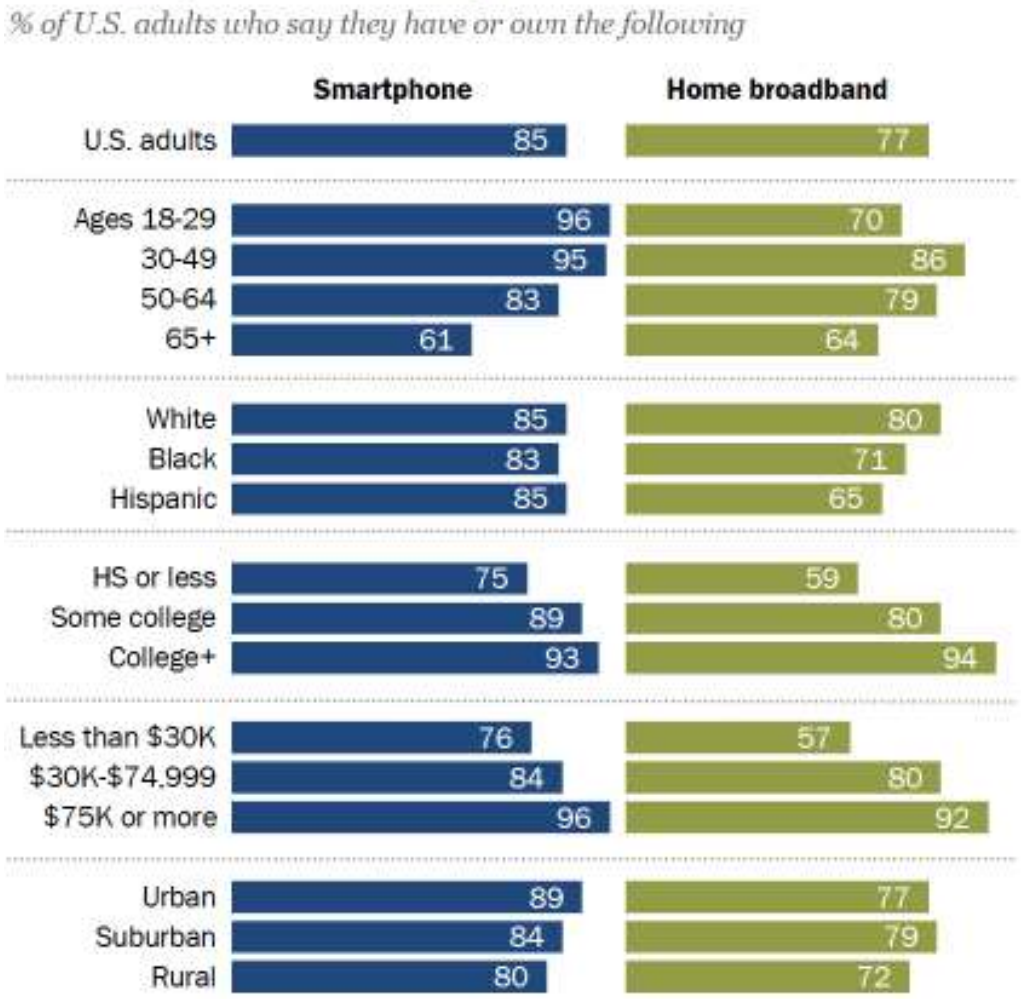
Source: A4ai.org




*Meaningful Connectivity*: the ability to use the internet every day using an appropriate device with enough data and a fast connection.

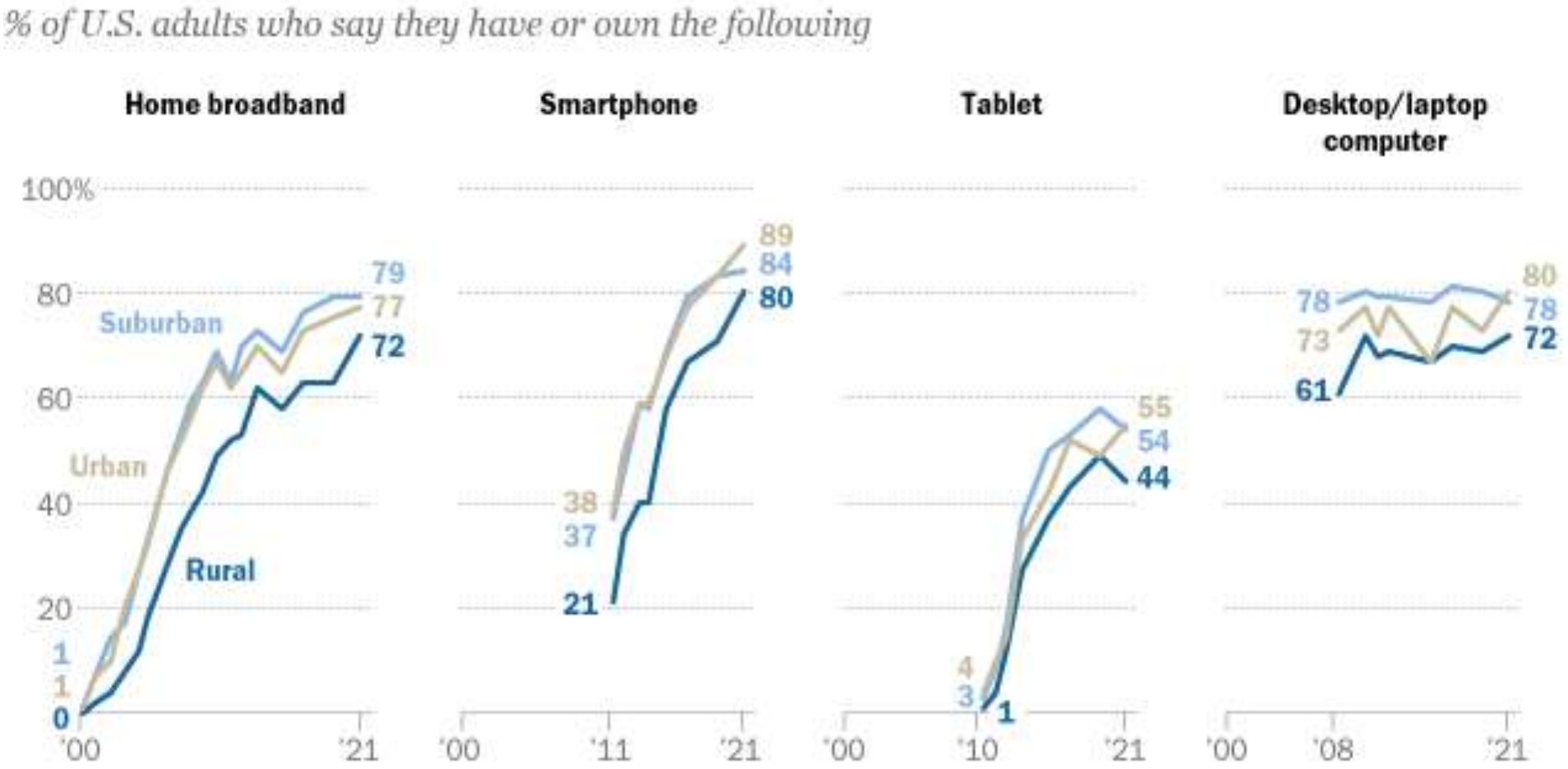
# US broadband, smartphone ownership variation and inequities: 2021 snapshot

- Age, race, education level, income, urban/rural differences
- Broadband differences greater than smartphone



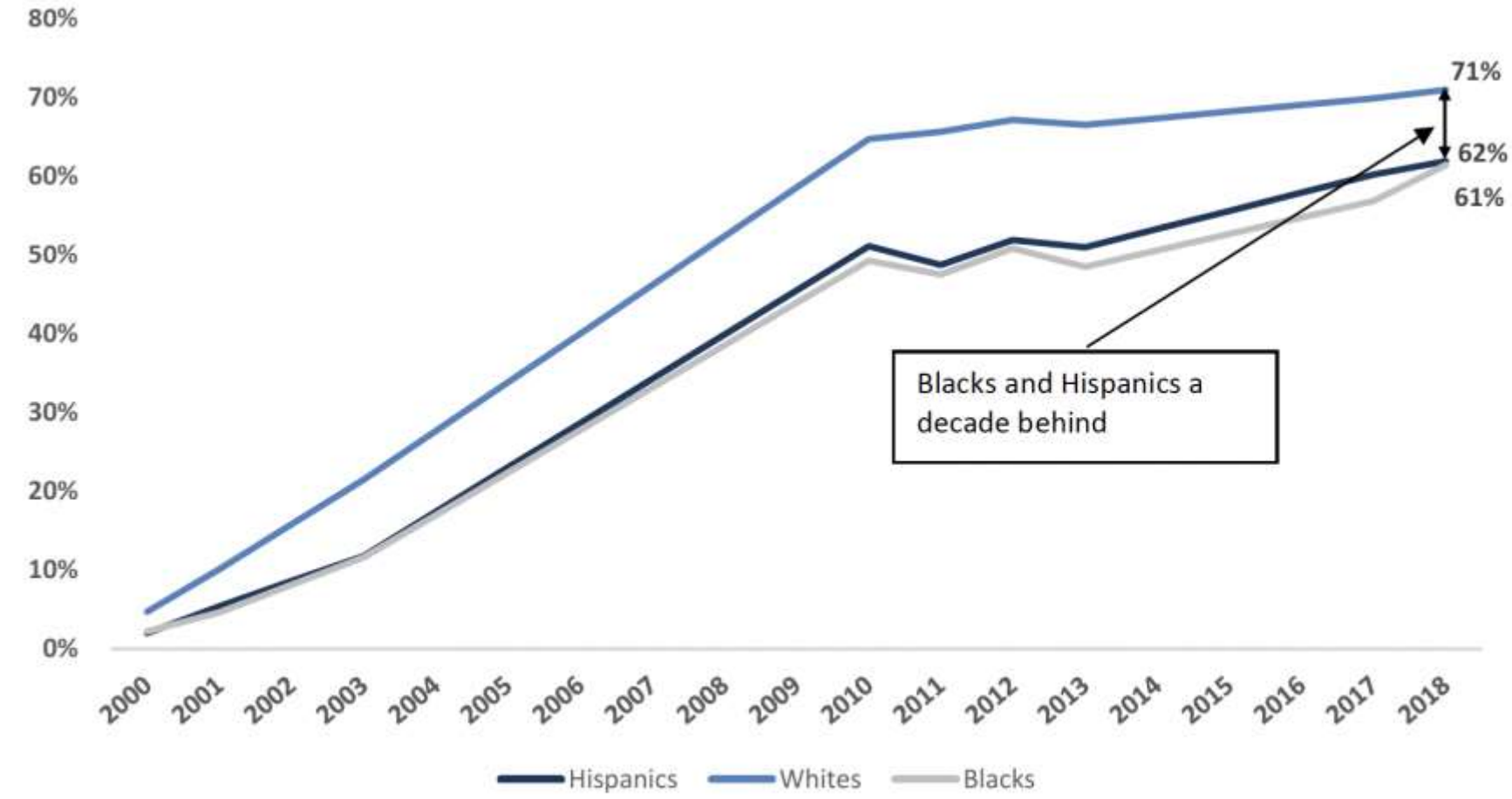

Feb. 2021, source: https://www.pewresearch.org/internet/2021/06/03/mobile-technology-and-home-broadband-2021/

# Changing US rural/urban “digital divide”



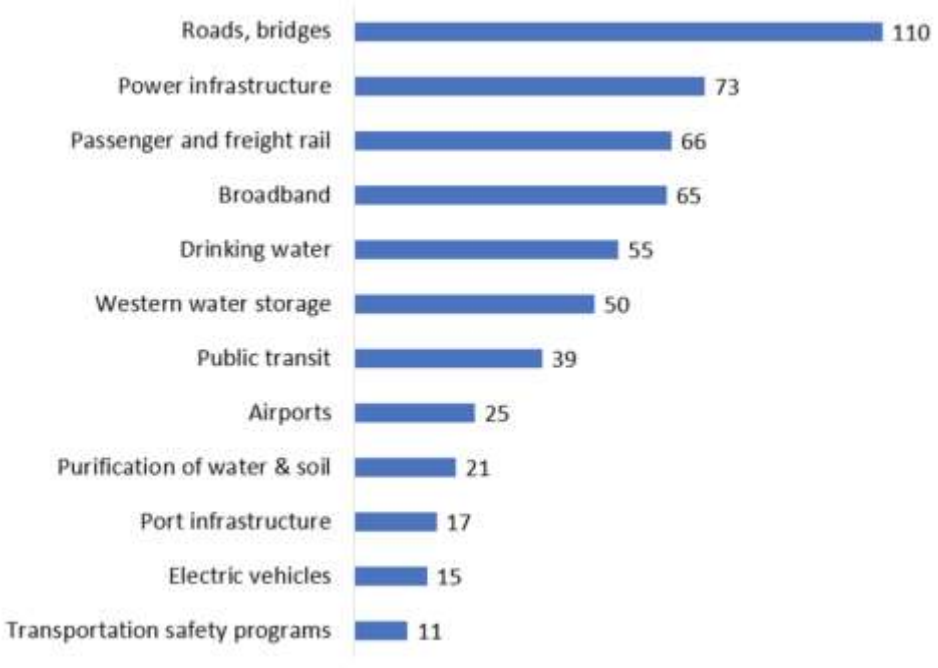

Feb. 2021, Source: https://www.pewresearch.org/fact-tank/2021/08/19/some-digital-divides-persist-between-rural-urban-and-suburban-america/

# Changing US racial “digital divide” over time




*Source : NTIA*

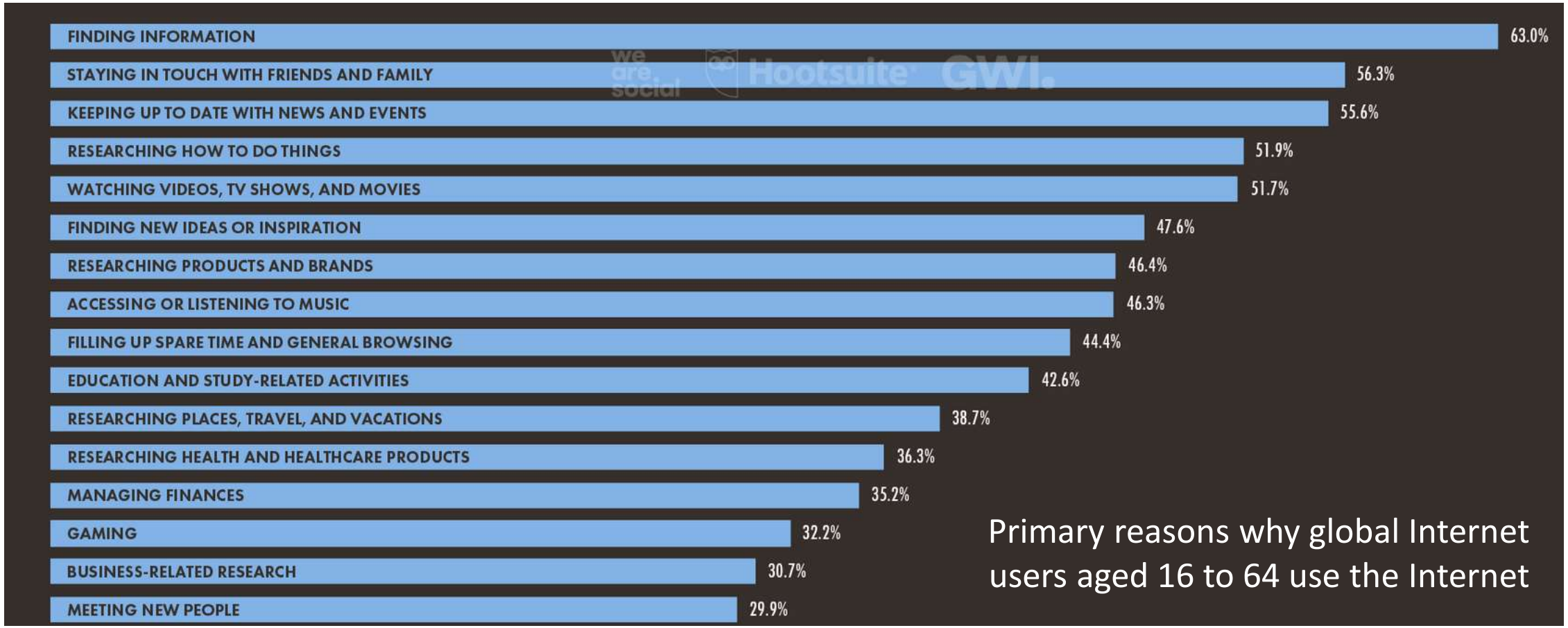
# 2021 US Infrastructure Investment and Jobs Act




*$65B investment in broadband*
(of $550B in total infrastructure investments, over 10 years)

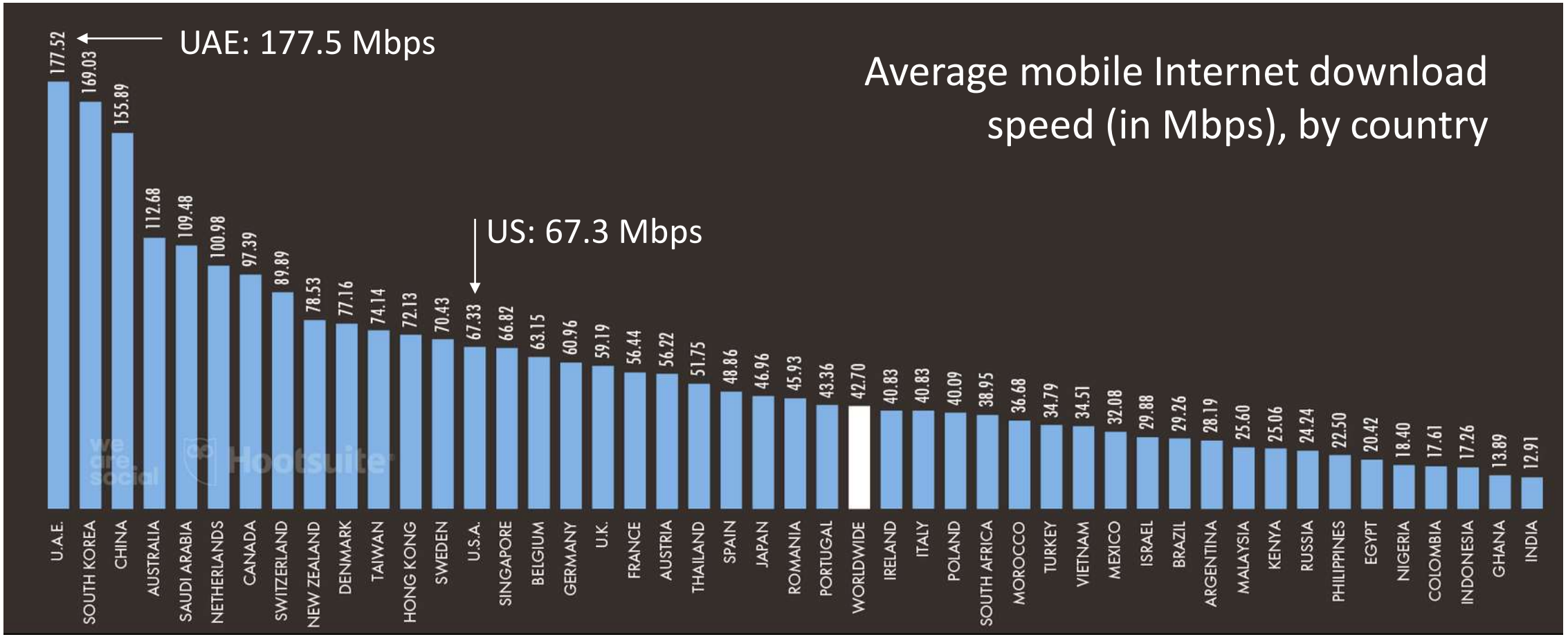
- **Broadband Equity, Access, and Deployment**. $42.5B in grants to states to expand broadband deployment in underserved areas
- **Affordable Connectivity Fund**. $14.2B. Up to $30/month reimbursement per household for broadband access cost
- **Digital Equity.** $2.75B to ensure "individuals and communities have the IT capacity that is needed for full participations in the society and economy of the US."
- **Tribal Broadband** Connectivity Program. $2B
- **Rural Utilities** ServiceReConnect. $2B

# Using the Internet




Jan. 2021, Source: https://datareportal.com/reports/digital-2021-global-overview-report

# Average mobile download access rates

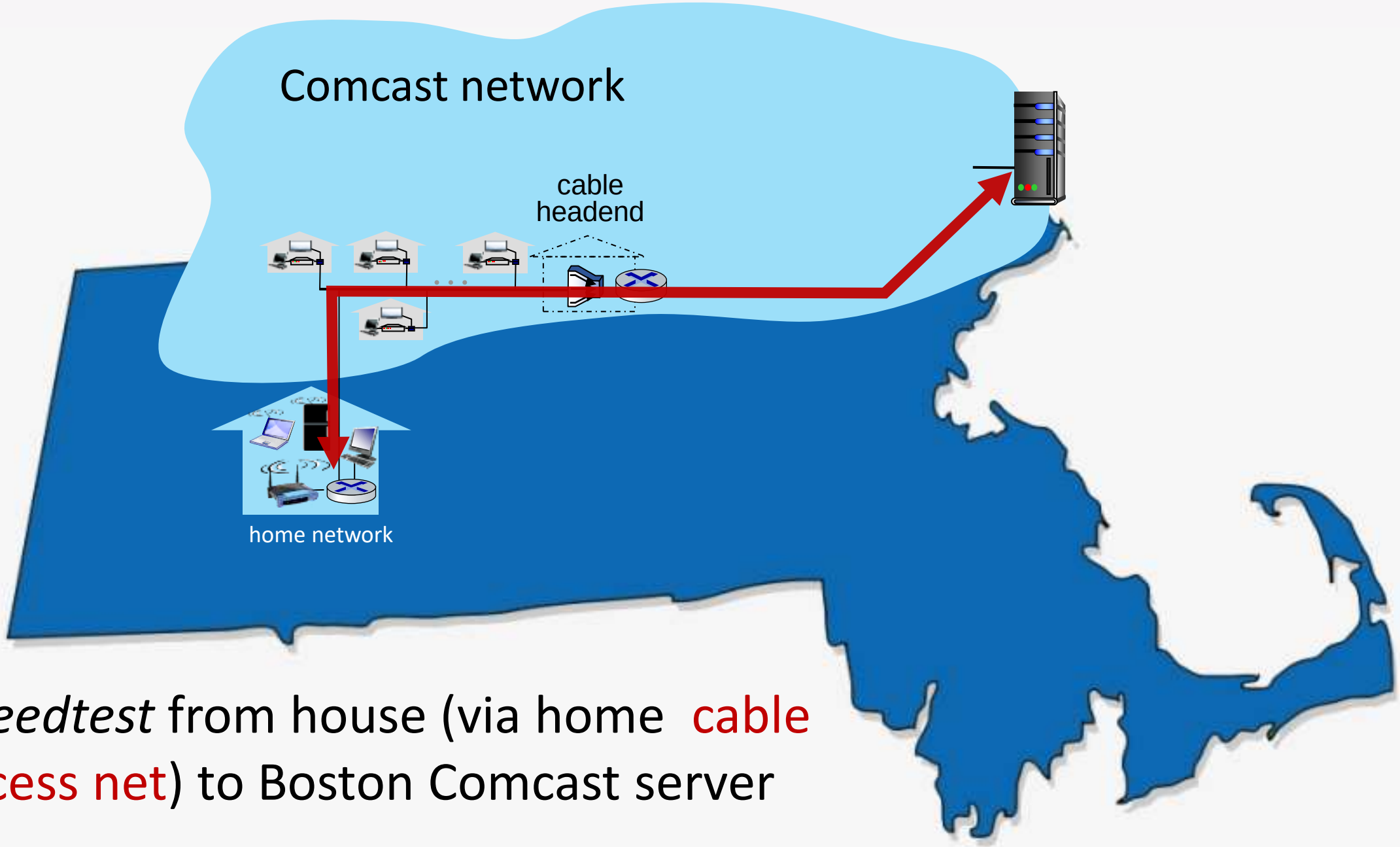



Jan. 2021, Source: https://datareportal.com/reports/digital-2021-global-overview-report

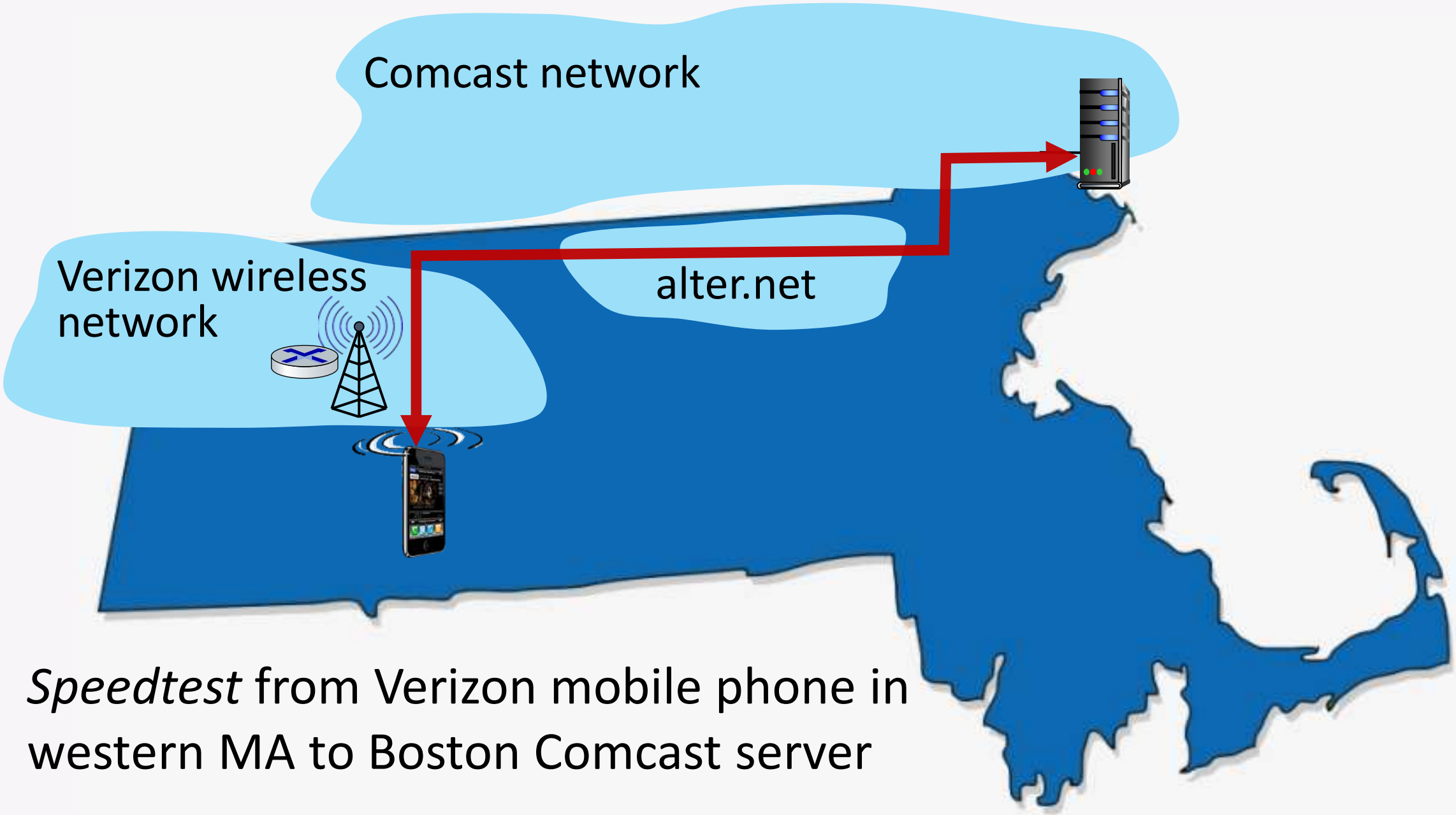
# “Who *uses* the Internet?”

## Questions to consider:

- Go to https://www.speedtest.net/ to measure your Internet access download speed. Try it from different places/devices if you can.
- If somebody were to turn off the internet, what would you miss most?
- How does Internet use change around the world?
- How much choice do you/your family have for home connectivity, among ISPs? How does the amount of choice vary by country?




*Speedtest* from house (via home cable access net) to Boston Comcast server



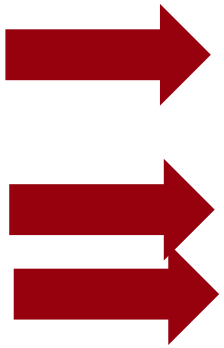

*Speedtest* from Verizon mobile phone in western MA to Boston Comcast server

# Who “controls” the Internet?

- ☐ INTERNET USERS
- ☐ INTERNET SERVICE PROVIDERS
- ☐ IT’S COMPLICATED
- ☐ IT’S *REALLY* COMPLICATED
- ☐ NATION STATES (COUNTRIES)
- ☐ UNITED NATIONS
- ☐ STANDARDS BODIES (e.g., IETF)
- ☐ INTERNET EQUIPMENT MANUFACTURES
- ☐ SKYNET INC.
- ☐ NON-PROFIT ORGANIZATION(S)

# "Who controls the Internet?"

- a great question, but ...
- analogies to other infrastructure: roads, railroads, water systems
  - regional, state, national, international governance
  - standards
  - role of industry, user groups, non-profits



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  - standards
  - role of industry, user groups, non-profits
- who are the "actors", who cares, and who makes decisions?
  - multistakeholder governance model
  - "tussle"/conflicts among actors "who care"

# Who "controls" the Internet: breaking the problem down

Reference model for discussing governance (different from Internet/OSI protocol stack):

V. Cerf, P. Ryan, M. Senges, "**Internet Governance Is Our Shared Responsibility"**
*I/S: A Journal of Law and Policy for the Information Society,* 10 ISJLP 1 (2014).

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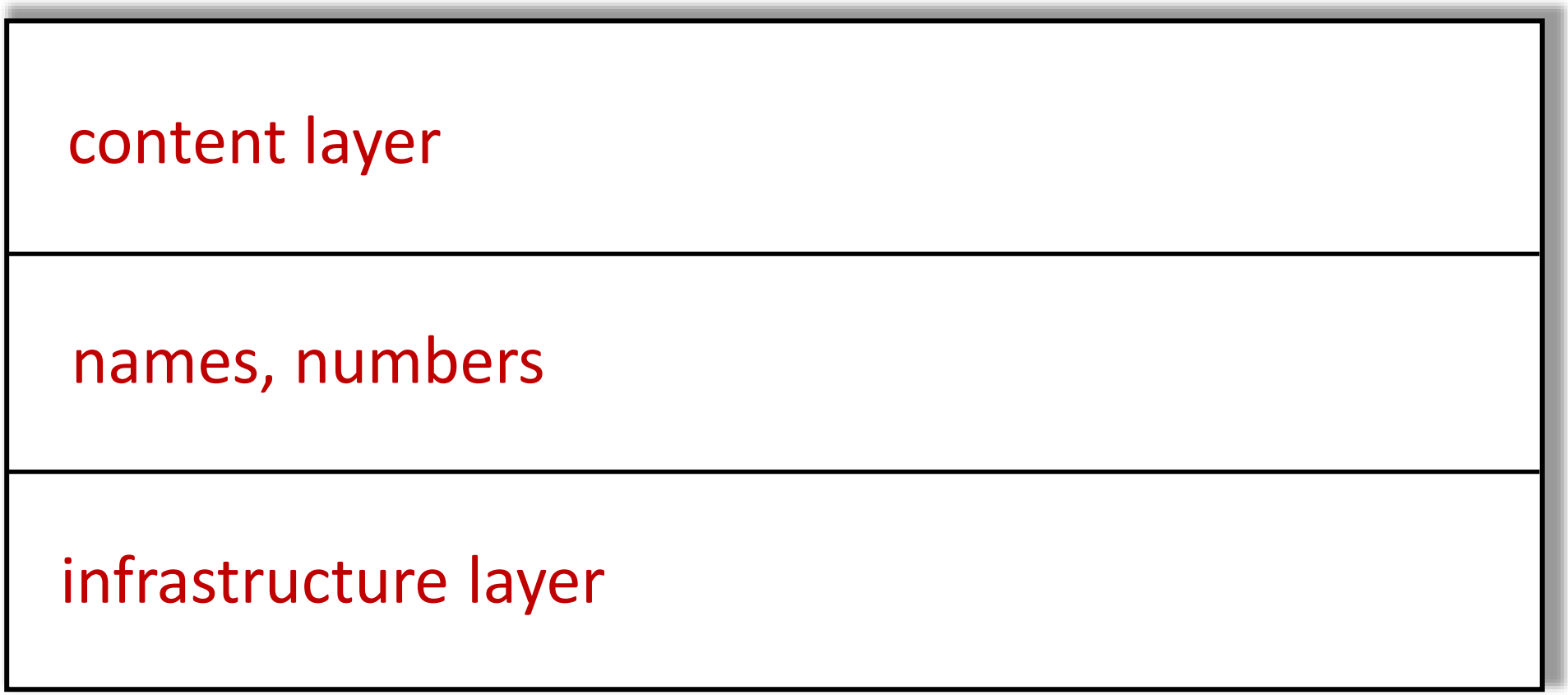

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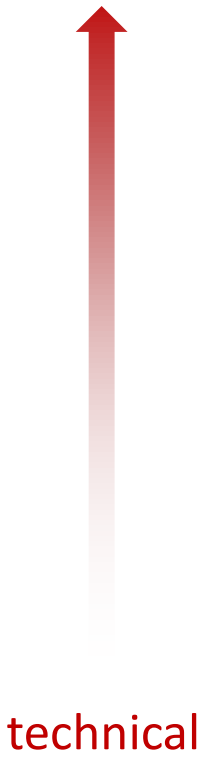
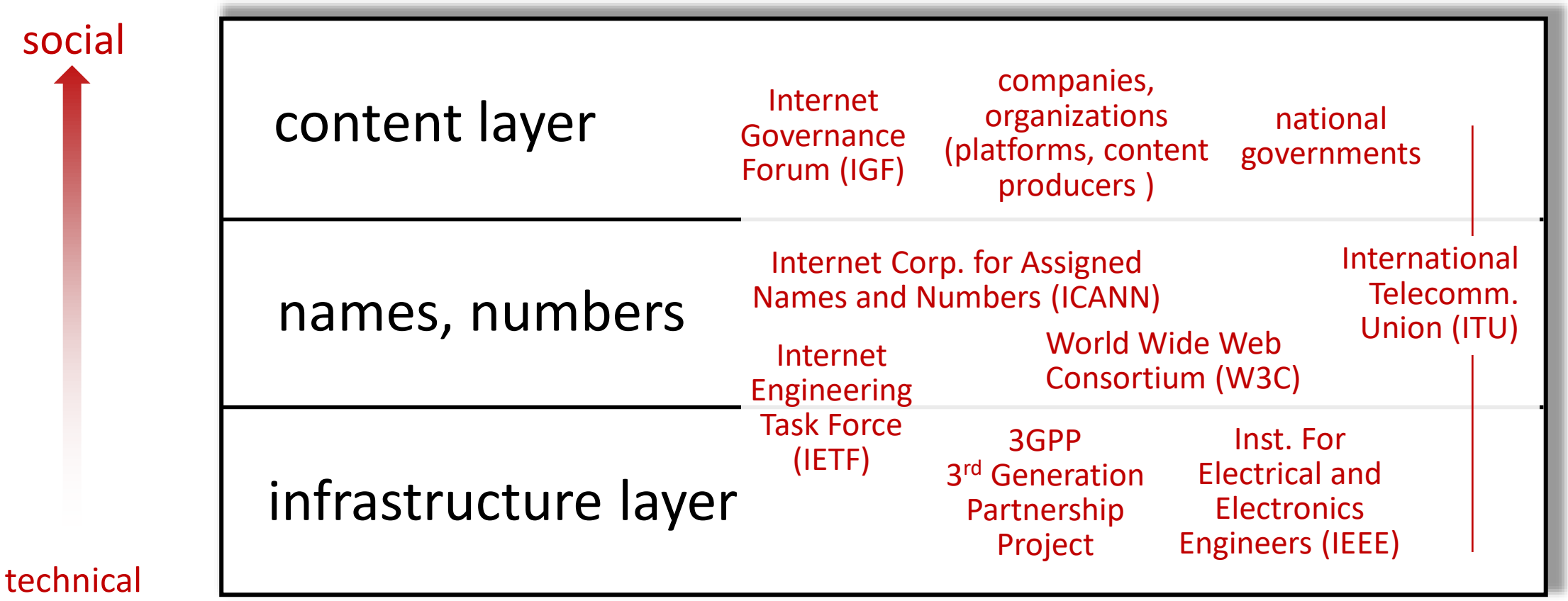



| | |
|---|---|
| content layer | Policy and social processes<br>▪ intellectual property<br>▪ content definition, filtering, regulation |
| names, numbers | Technical standards, and social processes for<br>▪ Internet names (e.g., www.umass.edu)<br>▪ Internet addresses (e.g., 128.119.40.186) |
| infrastructure layer | Technical *standards* for<br>▪ hardware: links, switches, routers<br>▪ protocols, message formats<br>▪ data formats (e.g., mp4) |

# Who "controls" the Internet: some of the players

Reference model (different than Internet/OSI protocol stack) for discussing issues:



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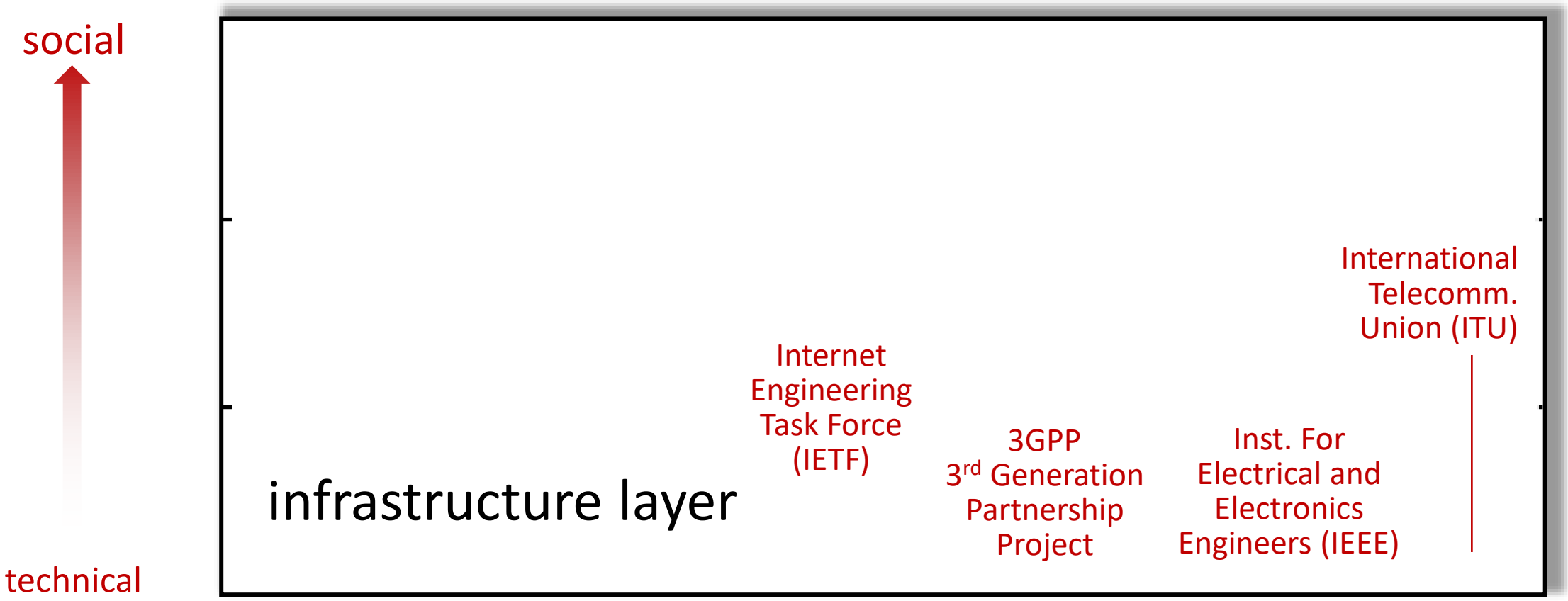
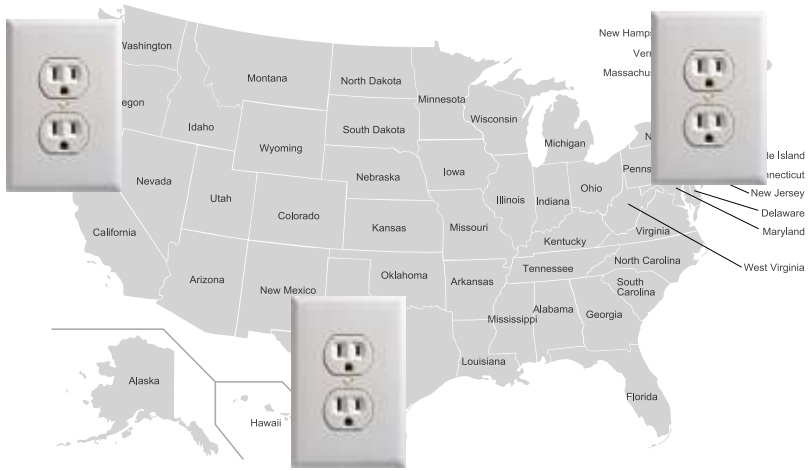
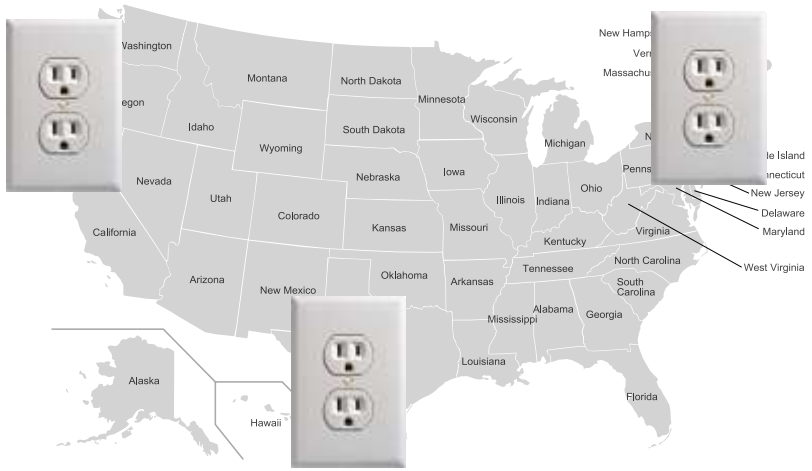


# Technical Standards: why standards?




110V, standard US electrical socket

# Technical Standards: why standards?




110V, standard US electrical socket

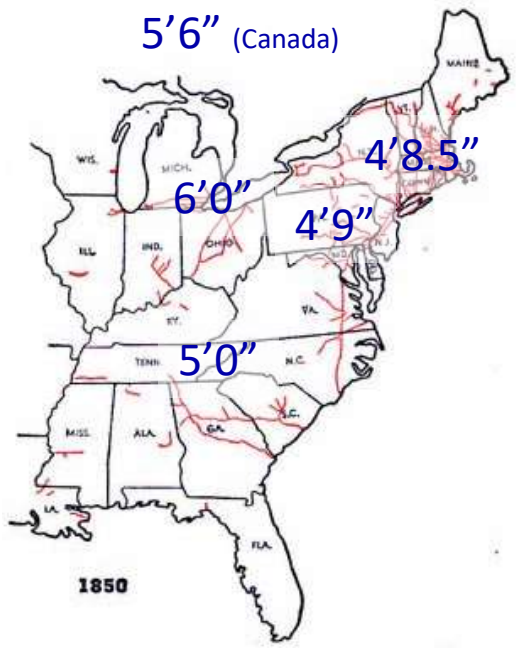
15 plug standards worldwide; 110V and 220V standards

Standards are needed for *interoperability* and *interconnectability*

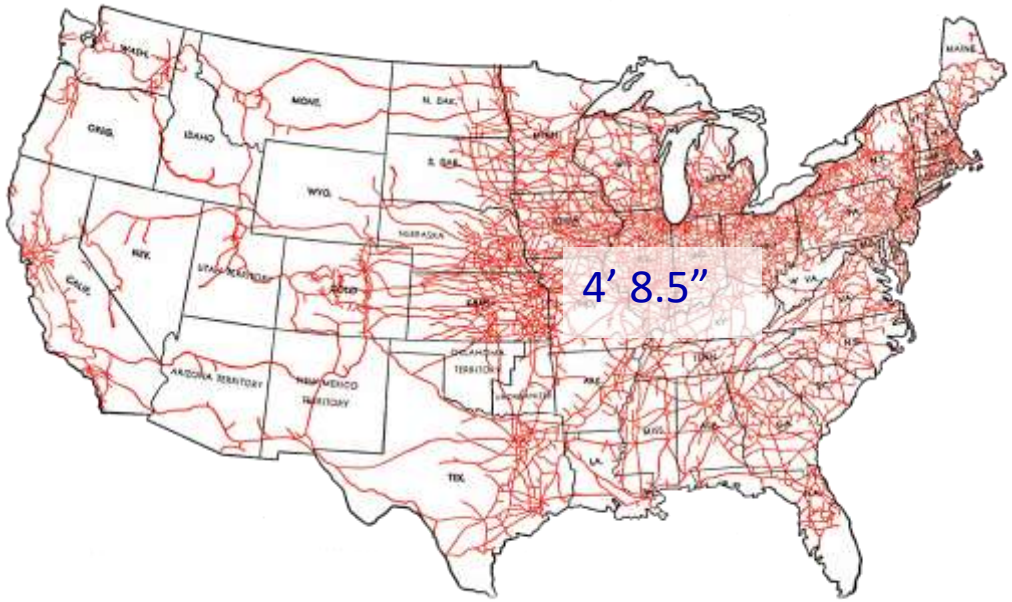
"…(s)tandards are one of the hallmarks of an industrial society. As the society becomes increasingly complex and its industrial base begins to emerge, it becomes necessary for the products, processes, and procedures of the society to fit together and to interoperate. This interoperation provides the basis for greater integration of the elements of society, which in turn causes increased social interdependency and complexity."

# Technical Standards: why standards?


railroad track gauge




1860: 20 different track gauges



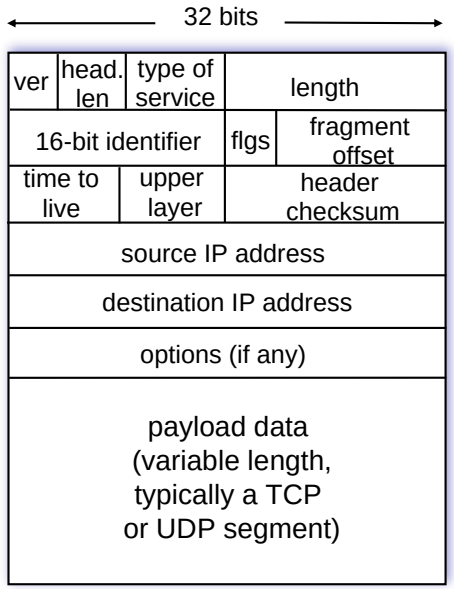

1886: a single 4’ 8.5” national track gauge standard

Fun with railroad standards:

- 1862: US gov’t convenes major railroad owners, standards discussed
- 1867: 29 railroad companies form Master Car Builders Association
- 1886: 4’ 8.5” standard gauge adopted
- Ties between 4’ 8.5” gauge, and ancient roman roads (e.g., Pompei)

# Internet Engineering Task Force (IETF, www.ietf.org)

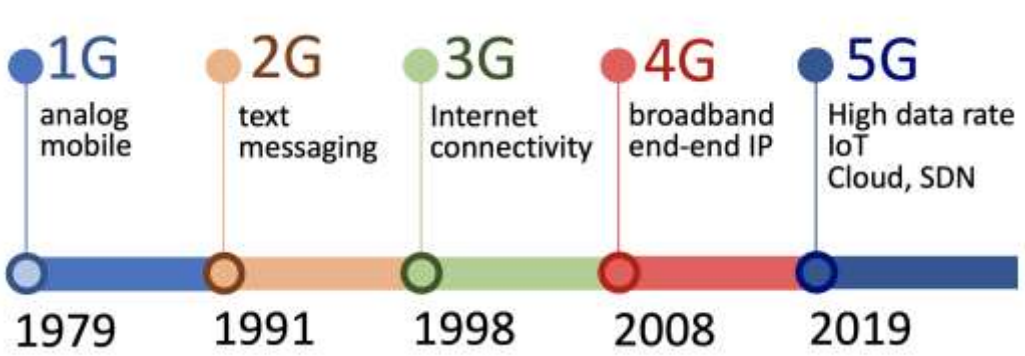
- *multiple stakeholders:* " ... a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet."
- *process:* working groups, twice a year open IETF meetings
  - "rough consensus and running code"
- Requests for Comments (RFCs)
  - "technical standards" defining Internet protocols (e.g., IP, TCP, UDP, HTTP)
  - > 9000 RFCs to date


IP datagram format (RFC 791)

# 3rd Generation Partnership Project (3GPP, www.3gpp.org)

- alliance of 7 global telecommunications standards groups
  - 745 member companies
- 16 working groups, in three technical areas:
  - radio access network
  - service/systems aspects
  - core network, terminals
- technical specifications:3G, 4G (LTE), 5G cellular networks
- 18 “releases” (like OS “release”), over three “generations”: 3G, 4G, 5G



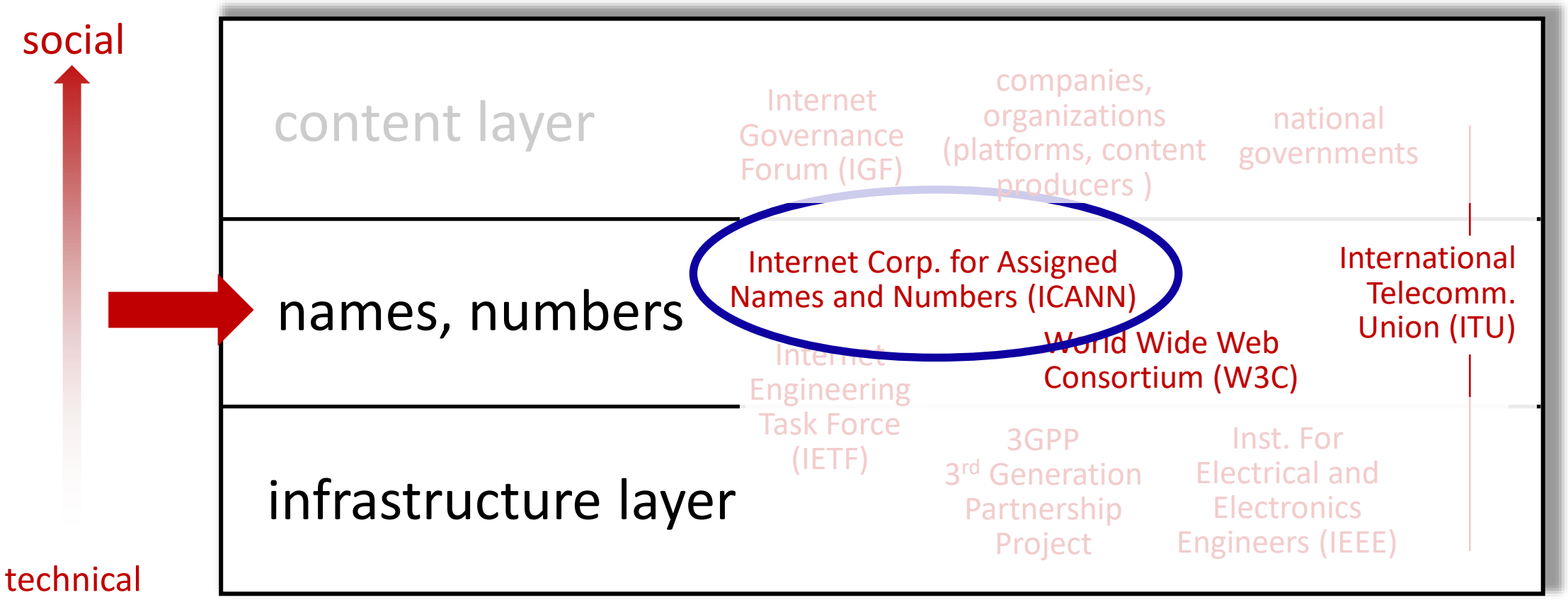
# IEEE standards

- IEEE: professional organization for electrical engineers
  - standards subgroup manages standards process, industry typically participates
- wired Ethernet standard (802.3)
- wireless WiFi standard (802.11)

# Int. Telecommunication Union (ITU)

- formed 1865 (not a typo!)
- telegraph, landline phone network standards
- United Nations agency since 1949
- 193 member countries, !900 companies
- not in the lead for Internet, mobile cellular networking

# Who "controls" the Internet: some of the players



# ICANN: Internet Corporation for Assigned Names and Numbers

- non-profit, multistakeholder organization
- handles (assigns, adjudicates) Internet names
  - e.g., www.umass.edu "belongs to" UMass Amherst campus
  - e.g., www.apple.com "belongs" to the Apple Corporation
  - What about .PATAGONIA? (region in South America, or outdoorsy company?)
  - What if someone creates JimKuroseIsAFlamingIdiot.com?

*Names are important!*

- *"A person's name is to that person, the sweetest, most important sound in any language." (Dale Carnegie)*
- *voice.com domain name sold for $30M in 2019*

- assigns Internet addresses to names, and manages translation between name and address (Domain Name System, more shortly)
  - e.g., www.cics.umass.edu has IP address 128.119.240.84

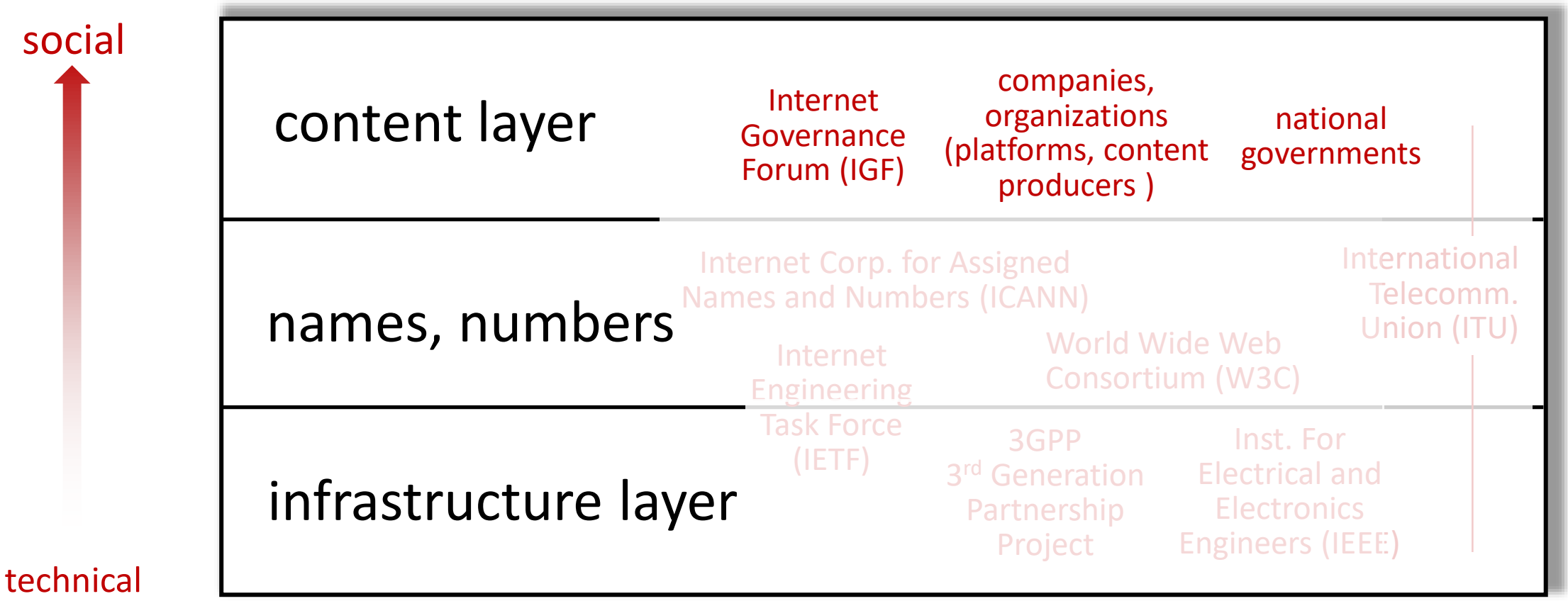
# ICANN: Internet Corporation for Assigned Names and Numbers

- non-profit, founded 1998 to internationalize Internet naming/addressing, previously overseen by U.S. gov't
- bottom-up, consensus-based multistakeholder processes
  - open meetings, anyone can address ICANN Board (e.g., in contrast to UN model)
  - governments have an equal voice with others, e.g., businesses, academics, and civil society (e.g., on advisory committees)
  - Board ... advised by four committees makes final decisions, following multiple public postings, reviews, discussion.
- increased pressure by some for more explicit *government* control
  - 2012 proposal (Russia, UAE, China, Saudi Arabia, Algeria, Sudan, Egypt in WCIT) required:

*"Member States [countries] shall have equal rights to manage the Internet, including ...."*

} argues for government supremacy in Internet control; no mention of other voices

# Who "controls" the Internet: some of the players



# IGF: Internet Governance Forum

- convened by UN secretary-general in 2006, renewed in 2015 for "multistakeholder policy dialogue"


- *does not make decisions*, but rather a deliberation body that "informs and inspires those who do"

*"Ultimately the involvement of all stakeholders, from developed as well as developing countries, from governments to international organisations, from the private sector to the civil society, is necessary for advancing dynamic public policies in Internet governance." [https://www.intgovforum.org]*

# Controlling the content layer: content providers


Millions of websites, services control *what* you experience - in some ways no differently than traditional media.

**"Section 230"** (47 U.S.C. § 230)**,** part of US Communications Decency Act, provides immunity for website platforms with respect to third-party content:

*"No provider or user of an interactive computer service shall be treated as the publisher or speaker of any information provided by another information content provider."*

*... more later*

# Controlling the content layer: governments

GLOBAL

*The Atlantic*

## The Anti-Information Age

How governments are reinventing censorship in the 21st century

By Moisés Naím and Philip Bennett

The New York Times (Apr. 2019)

## *Kremlin Moves Toward Control of Internet, Raising Censorship Fears*

The New York Times (Jan. 2022)

## *Cambodia's Internet May Soon Be Like China's: State-Controlled*

Under a new decree, all web traffic will be routed through a government portal. Rights groups say a crackdown on digital expression is about to get worse.

The Washington Post
*Democracy Dies in Darkness*

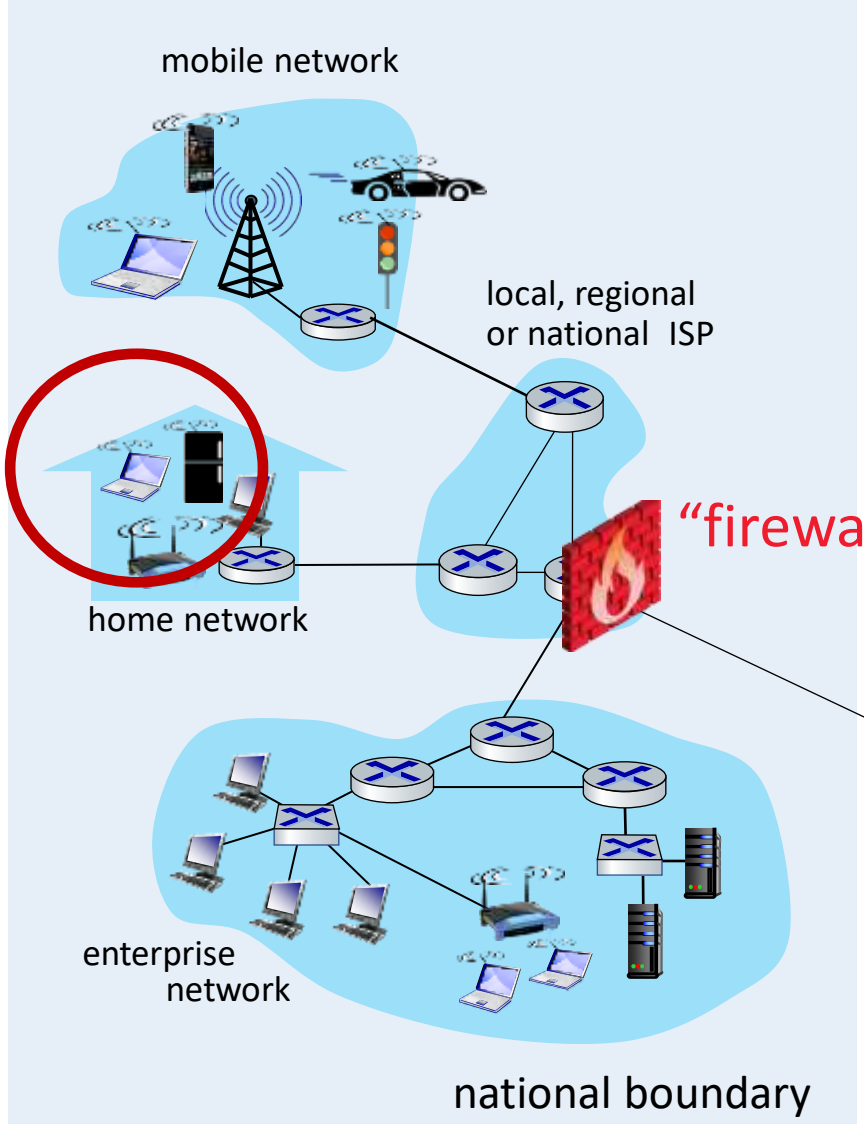
World

## Under Vietnam's new cybersecurity law, U.S. tech giants face stricter censorship

The country is seen as an emerging e-commerce "dragon." But it's also one of the most restrictive.

**By Timothy McLaughlin** *March 16, 2019 at 5:07 PM EDT*

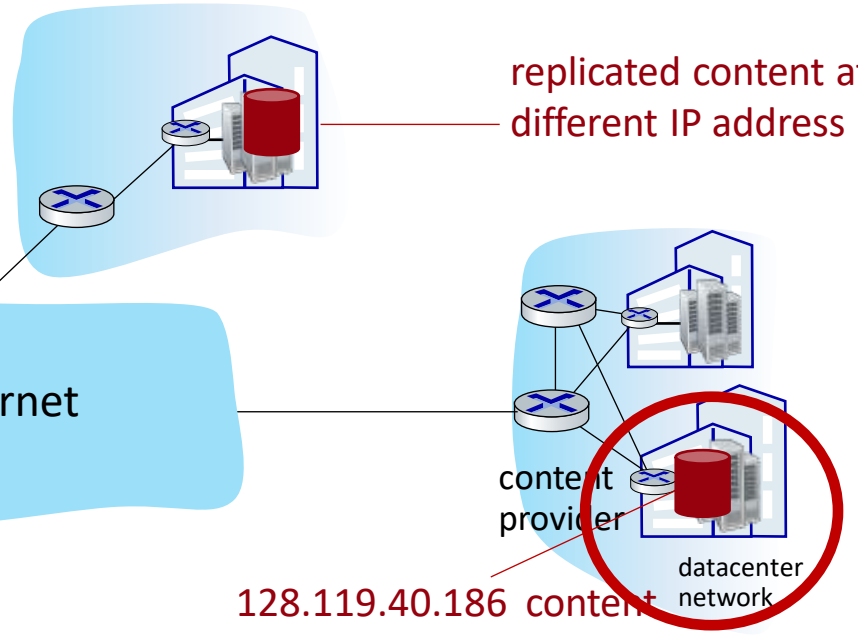
# Controlling content flow: a network perspective




*firewall:* mechanism to control content access via programmable *rules*:

- "don't forward any packets to 128.118.40.186"
- "don't forward any packets containing the phrase *X* anywhere"

*... more later*



# "Who *does* control the Internet?"

Questions to consider:

- Which governance roles are global, which are more local?
- Which stakeholders are becoming more or less influential over time?
- How is Internet governance different from railroad, or phone (landline) network governance?
- How is Internet governance different from, or similar to, press/media control/governance?