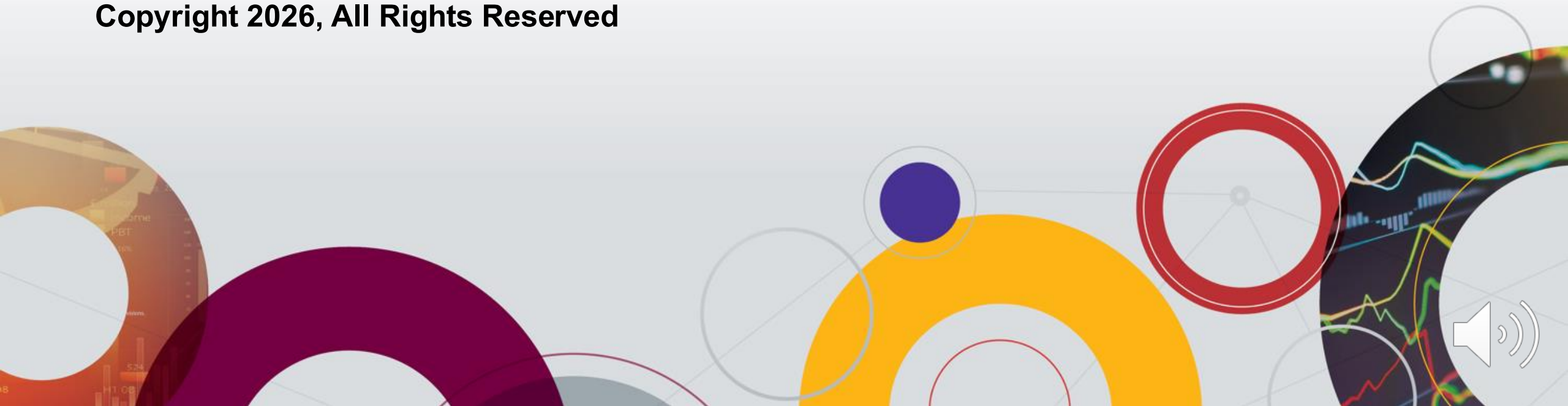


2.4a Computer Networks

10x10 – Introduction to Biomedical Informatics & Artificial Intelligence
William Hersh, MD, FACMI, FAMIA, FIAHSI
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Computer networks – overview

Basic principles

Internet

Wireless networks

World Wide Web

Evolution of the Web

Biomedical and health applications on the Internet

Social networks



Computer networks

Most rapidly evolving and expanding computer technology today is the network

“The value of a network increases exponentially with the number of nodes”

- Bob Metcalfe, inventor of Ethernet, 1980s

“Videotex” in our homes, according to NSF report (Reinhold, 1982)

Advertisements from the 1990s

- “The network is the computer” – Sun Microsystems
- AT&T [“You will” ad campaign](#)

“It’s the network, stupid”

- Anonymous

Computers on networks

Basic communications protocol is Transmission Control Protocol/Internet Protocol (TCP/IP)

TCP/IP sends data in packets

- Different packets may arrive at the destination by different pathways and in different order
- TCP protocol helps insure that all data is received, and that it is put into the proper order
- IP address is network location where packets are sent or received

Unlike telephones, TCP/IP connections do not establish dedicated circuit

Routers are critical devices that route TCP/IP traffic to appropriate places on networks

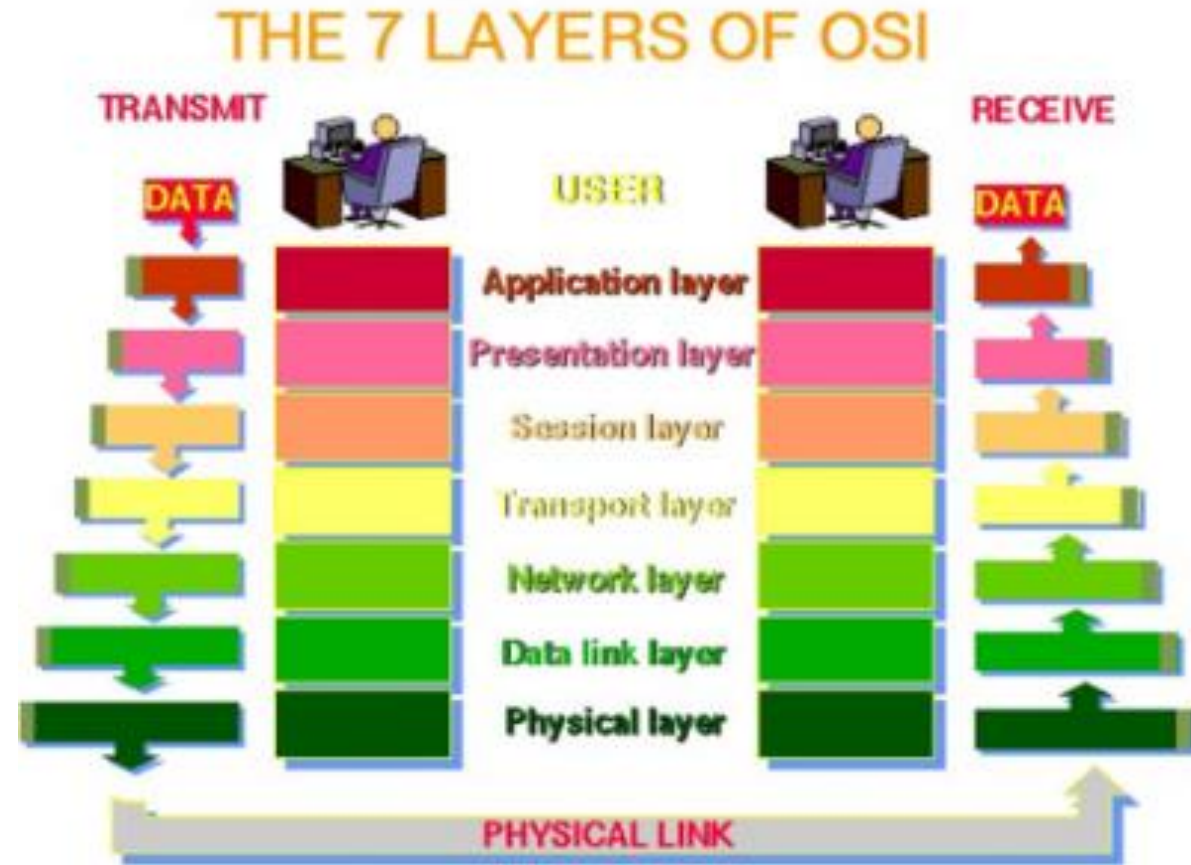


Architecture of computer networks

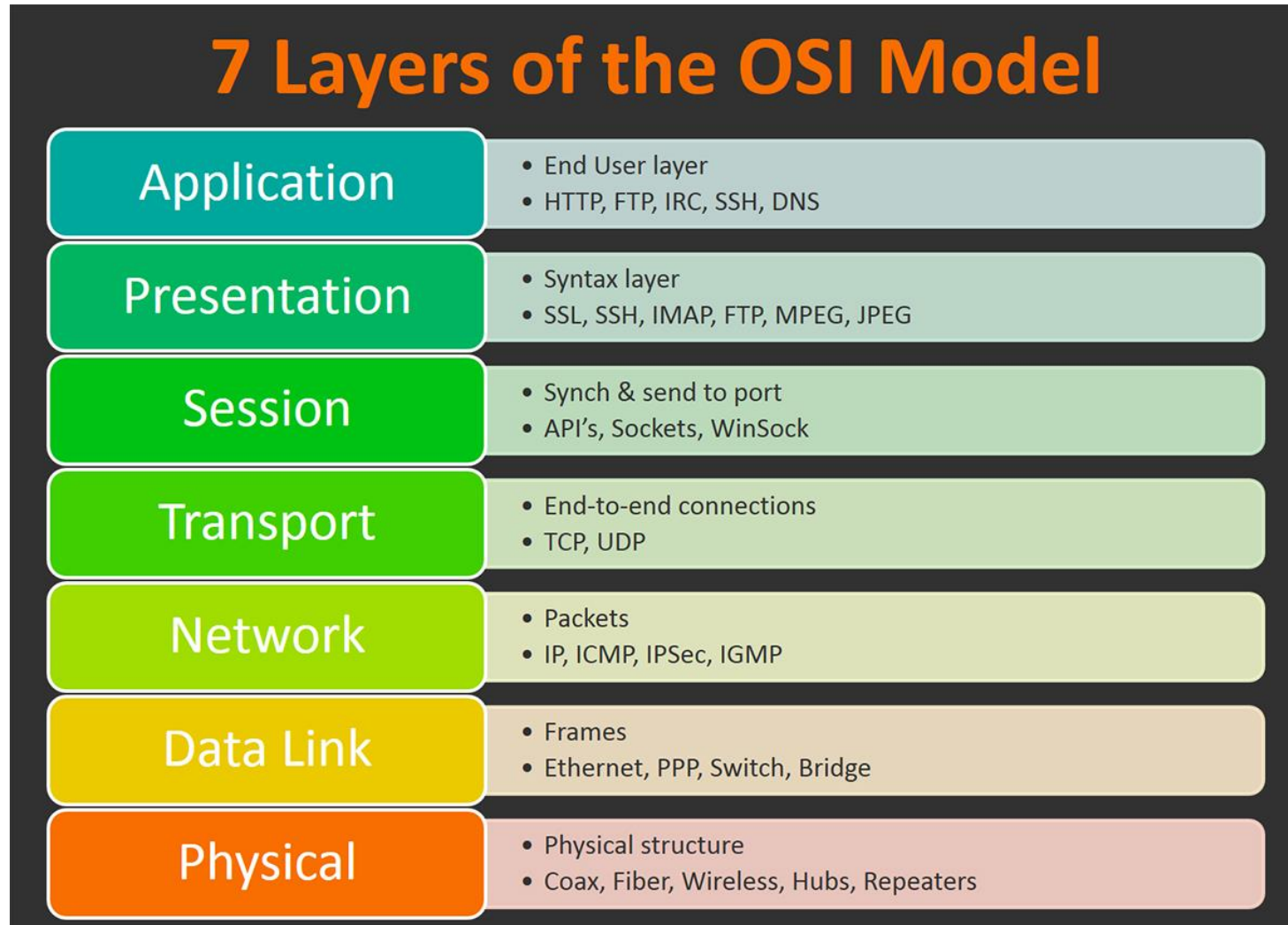
Based on seven-layer Open Systems Interconnection (OSI) Reference Model

Provides abstractions for functions at different levels, so developer need not worry about lower-level details

TCP/IP has some inherent limitations, e.g., no means to prioritize traffic, no built-in security, etc.



Services at different levels of OSI model (Raza, 2018)



Analogy to sending a letter

Layer	Name	What It Does	Example
7	Application	This is where you use apps like email or games.	You write a letter to your friend.
6	Presentation	Makes sure the message looks right and is readable.	You write in English so your friend understands.
5	Session	Starts and ends the conversation between computers.	You say "Hi!" and start chatting.
4	Transport	Breaks your message into smaller pieces and checks if it got there safely.	You put your letter in an envelope and make sure it is sealed.
3	Network	Finds the best path to send your message.	The mail truck decides the fastest route to your friend's house.
2	Data Link	Gets your message ready to travel on wires or Wi-Fi.	The mail carrier puts your letter in the right mailbox.
1	Physical	Sends the actual message using electricity, light, or radio waves.	The mail carrier walks or drives to deliver your letter.

Some older networking terms and concepts

Local-area network (LAN) is network in single location

- May consist of a few computers connected to a common printer or hundreds of connected devices

Wide-area network (WAN) interconnects multiple LANs over large distances

Client-server architecture

- Client computer is user's machine which interacts with user and formats information
- Server computer processes transactions
- Evolving middleware belies simple model

Networking speeds or bandwidth

Typically measured in bits per second (Bps, used to be called baud)

Original telephone modems operated at 120-56,000 bits per second or baud

- Fastest modems were 56 kilobaud (Kbps)

Computer networks typically operate at megabit speeds, e.g., current home broadband 1 to hundreds of megabits per second (Mbps), limited by slowest step along the route

Recent speeds in “gigabit” range, e.g., Gbps

Recent world data transmission record 1.8 Pbps (Krull, 2022)

For networking speeds, 1 Kbps = 1000 bps, 1 Mbps = 1000 Kbps, etc.

- But most network connections shared, so “actual performance may vary”
- [Test your own speed](#)

Wireless networks

Have become ubiquitous in and out of healthcare

Connected to a wired network by a wireless access point (WAP)

- WAP to computer speed may be fast but can be slowed by other steps along the Internet

Ease of use challenged by security concerns

- Many sites leave their networks wide open, perhaps too open, relying on security of connected computers

History of wireless communications (Launianen, 2018)

WiFi standards revolve around IEEE 802.11 family of protocols (IEEE, 2023)

Name	Bandwidth	Generation	Issues
802.11a	54 Mbps	WiFi 1	Signals cannot penetrate walls and other barriers well
802.11b	11 Mbps	WiFi 2	Wireless Encryption Protocol (WEP) highly flawed
802.11g	54 Mbps	WiFi 3	“Upgrade” of 802.11b to fix previous problems
802.11n	Up to 600 Mbps	WiFi 4	Further enhancement in bandwidth and distance
802.11ac	Up to 1 Gbps	WiFi 5	First to allow use of multiple antennas
802.11ax	Up to 9.6 Gbps	WiFi 6	Added more reliability
802.11be	Up to 40 Gbps	WiFi 7	Newest, just starting commercial uptake



Mobile broadband, aka cell phone networks

Protocol	Typical Bandwidth	Comments
2G (1x)	1 Mbps	Original digital cell network
3G	2 Mbps	First widely used standard
4G LTE	100 Mbps	Currently used in most countries
5G	Up to 10-20 Gbps	Three levels (Blumenthal, 2022): • Low band – extension of 4G LTE • Midband – also called C-band, up to 1 Gbps • Millimeter wave – fastest but shortest range, up to 10-20 Gbps



Other wireless standards

Bluetooth – for low-bandwidth, short-range transfer of small amounts of data between devices

- Examples include
 - Mouse to computer
 - Cell phone to earpiece
 - Smartphone to smartwatch
- Lower power and data speeds: data transmission ~80kbps with range of 10m

Radio-frequency identification (RFID) – electromagnetic fields that identify and track tags attached to objects

- Including things connected to objects in healthcare

Near-field communication (NFC) – set of communication protocols that enable two electronic devices to communicate by bringing them within 4 cm of each other

- Most common use is cell phone payments

The Internet

Worldwide computer network bound together by TCP/IP

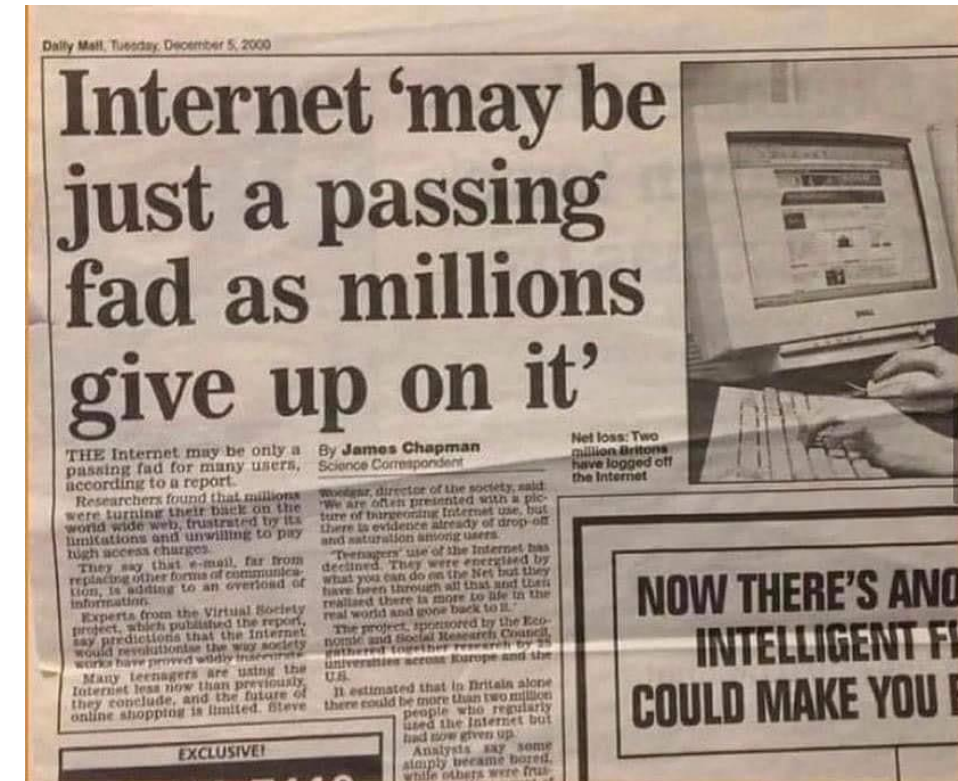
Not a single network, but many “internetworks”

Centralized engineering decisions made by [Internet Engineering Task Force \(IETF\)](#)

Top-level domain names administered by [Internet Corporation For Assigned Names and Numbers \(ICANN\)](#)

- ICANN was originally under US governance but is now under international governance (Moyer, 2016)

Books on history (McCullough, 2018) and future design considerations (Clark, 2018)



Internet names and addresses

Every device on the Internet has an Internet Protocol (IP) address

- In IP v4, each address has four 8-bit numbers (limited to about 4.3 billion addresses)
- Increased to four 32-bit numbers in IP v6
- Most end-user IP addresses assigned dynamically, including multiple devices within a network connected to a single server using Dynamic Host Configuration Protocol (DHCP)

Addresses mapped to names by Domain Name System (DNS)

- DNS converts name to IP address, e.g., www.ohsu.edu to 137.53.1.30
- DNS servers across Internet are updated in a distributed fashion

Internet-related terms

Intranet – Network local to organization that uses Internet technology

Extranet – Network limited to associates of an organization

Virtual private network (VPN) – the “new” WAN, allows distant network to appear local and protect security

Coming full circle: Voice over IP (VOIP) uses TCP/IP for voice transmissions, i.e., telephone

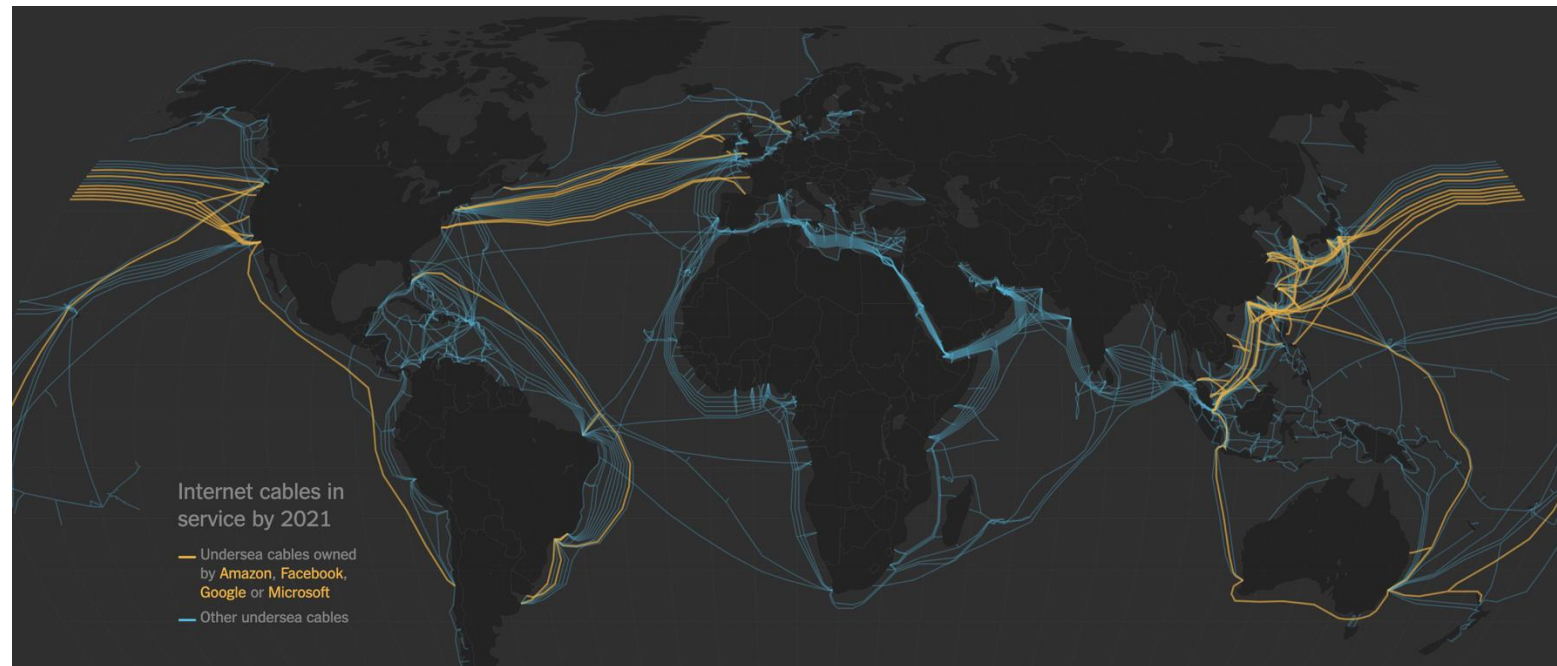
- Most have used it, e.g., WhatsApp
- Merger of voice and data, i.e., voice becoming just another form of data

World Internet access is ubiquitous and important for health

“People think the data is in the cloud, but... it’s in the ocean” (Satariano, 2019)

Satellite (e.g., Starlink) Internet is promising but best for less dense areas (Meinrath, 2025)

Estimated users worldwide is 5.44 billion (Petrosyan, 2025)



Internet in the US

Most up-to-date data come from Pew Research Center

- [Internet and broadband](#)
- [Mobile](#)

As of 2024, US Internet and mobile usage

- 96% of adults
- Across all age groups – 98-99% of ages 18-29, 30-49, and 50-64, down to 90% of age 65+
- 79% with home broadband – 15% with smartphone only
- 98% with cell phone, 91% with smartphone

Ownership of devices (Vogels, 2021)

- Desktop/laptop computer – 72-80%
- Tablet – 44-55%
- Somewhat lower in rural than urban or suburban areas